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An Investigation into Factors Influencing the Sensory Properties of Selected Irish Grown Organic and Conventional Vegetables

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An Investigation into Factors Influencing the Sensory Properties of Selected Irish Grown Organic and Conventional Vegetables

A THESIS SUBMITTED TO DUBLIN INSTITUTE OF TECHNOLOGY IN

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DOCTOR OF PHILOSOPHY

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DECLARATION

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ABSTRACT

Research studies conducted on organic produce have given conflicting results whether they have superior sensory qualities when compared to conventionally cultivated produce. The development and implementation of a reliable testing system is therefore required. In this study Irish grown organic and conventional carrots (*cv.* Nairobi), potatoes (*cv.* Orla) and tomatoes (*cv.* Amoroso) were selected for physicochemical (size, colour, dry matter, texture, sugars, ^{o}Brix & pH), volatile emissions and sensory analysis (trained and consumer panels). All vegetables were tested in both a raw and cooked state. Few significant differences were apparent between the organic and conventional vegetables for the physicochemical components, volatile emissions and sensory properties. No significant differences were evident between the organic and conventional carrots (raw or steamed) for any of the instrumental or sensory parameters tested. The organic growing conditions appeared to have a significant impact on the texture ($p \leq 0.05$) of the raw and baked potatoes, but did not appear to affect appearance, taste or consumer acceptability of baked potatoes. The conventional tomatoes (raw or cooked) were perceived to be sweeter ($p \leq 0.05$), and contained higher quantities of glucose and fructose ($p \leq 0.05$) compared to the organic tomatoes (raw or cooked). Nonetheless, no significant differences were found between the organic and conventional tomatoes for appearance and texture. The sensory quality of the organic vegetables was very similar to that of the conventional vegetables.

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For Mam and Dad, you believed in me when I didn’t.

Thank you!

ABBREVIATIONS AND SYMBOLS

ac	acres
amu	atomic mass unit
AOAC	Association of Analytical Communities
B	Boron
^{o}Brix	degrees Brix
β-carotene	beta-carotene
B.S.E	Bovine Spongiform Encephalopathy
c	concentration
C*	chroma
^{o}C	degrees Celsius
$Ca(NO_3)_2$	Calcium nitrate
CIE	Commission International de l’Eclairage
cm	centimeter
CO_2	carbon dioxide
CSO	Central Statistics Office Ireland
Cu	Copper
cv	cultivar
C-value	cylindrical form of the root
d	light path
DAFF	Department of Agriculture, Fisheries and Food
dS	dissolved solids
DIT	Dublin Institute of Technology
EC	electrical conductivity
EC	European Communities
EU	European Union
eV	electron-volt
FAOSTAT	Food and Agriculture Organisation Statistical Database
Fe	Iron
FiBL	Forschungsinstitut fûr Biologischen Landbau; Research Institute of Organic Agriculture

FSAI	Food Safety Authority of Ireland
FW	fresh weight
g	grams
GC	gas-chromatography; gas chromatograph
GC-MS	gas chromatography-mass spectrometry; gas chromatograph-mass spectrometer
g/L	grams per litre
g/100g FW	grams per 100 grams fresh weight
h	hours
H*	Hue angle
ha	hectare
IFOAM	International Federation of Organic Agriculture Movements
IOFGA	Irish Organic Farmers and Growers Association
ISO	International Organisation for Standardisation
K	Potassium
K_2SO_4	Potassium sulfate
kg	kilogram
kg ha^{-1}	kilograms per hectare
kg K ha^{-1}	kilograms of potassium per hectare
kg N ha^{-1}	kilograms of nitrogen per hectare
kg P ha^{-1}	kilograms of phosphorus per hectare
KNO_3	Potassium nitrate
L	litre
l	length in cm
L ha^{-1}	litres per hectare
LOX	Lipoxgenase
m^2	meters squared
Mg	Magnesium
$MgSO_4$	Magnesium sulfate
min	minutes
ml	millilitres

mm	millimetres
mm^2	millimetres squared
mm/min	millimetres per minute
Mn	Manganese
Mo	Molybdenum
MS	mass spectrometry; mass spectrometer, mass spectrum
MW	molecular weight
m/z	mass to charge ratio
N	newtons; Nitrogen
NaCl	Sodium chloride
$NADP^+$/ATP	nicotinamide-adenine dinucleotide phosphate/adenosine-5-triphosphate
$(NH_2)_2CO$	Urea
NH_4^+	Ammonium
$(NH_4)(NO_3)$	Ammonium nitrate
$(NH_4)_2SO_4$	Ammonium sulphate
NIST	National Institute of Standards and Technology
N-P-K	Nitrogen-Phosphorus-Potassium
NO_2^-	Nitrite
NO_3^-	Nitrate
OPP	orientated polypropylene
P	Phosphorus
PCS	Pesticide Control Service
PDMS	polydimethylsiloxane
P-K	Phosphorus-Potassium
ppm	parts per million
PVC	Polyvinyl chloride
r	radius
rpm	rotations per minute
SI	Statutory Instrument
SPME	solid-phase micro-extraction

SPSS	Statistical Package for Social Scientists
t	tonnes
t ha^{-1}	tonnes per hectare
μg	micrograms
μm	micrometers
μS	microSiemens
UV/VIS	Ultraviolet-Visible Spectroscopy
v	sample volume
V	final volume
W	weight in grams
w/w	weight for weight
Zn	zinc
α	alpha
β	beta
γ	gamma
δ	delta
ε	extinction coefficient of NADPH at 340nm
€	euro
≥	Greater than or equal to
≤	Less than or equal to

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CHAPTER 1

1.1 GENERAL INTRODUCTION

Organically farmed foods have seen a significant rise in popularity worldwide over the past decade, with the global market for organic food estimated at €33 billion in 2007 (Sahota, 2009). In Ireland, sales of organic food increased considerably (13%) from €104 million to €124 million between 2008 and 2009 (Bord Bia, 2009a). This increased preference for organically farmed food is attributable to the perception that it is healthier, tastier, safer and more environmentally friendly than conventionally produced food (Bourn and Prescott, 2002; Bord Bia, 2003; Magkos *et al*. 2006; Winter and Davis, 2006). Organic agriculture is characterised as a system of farming, which focuses on the use of renewable resources and preservation of the environment, but avoids or largely excludes the use of synthetically-produced chemicals or fertilisers, herbicides, insecticides, fungicides, or any other pesticides, growth hormones or growth regulators (Codex Alimentarius Commission, 2001). In Ireland, organic vegetables comprise the largest segment of the organic food sector with carrots, potatoes and tomatoes being the most popular vegetables purchased by consumers in 2008 (Bord Bia, 2008b). There is a growing volume of literature comparing the sensory quality of organically farmed and conventionally produced vegetables (Basker, 1992; Hajšlová *et al*., 2005; Wszelaki *et al*., 2005; Barrett *et al*., 2007; Zhao *et al*., 2007). However to date, research studies conducted on organic vegetables have given conflicting results on whether they have superior sensory quality when compared to conventional vegetables (Woese et al., 1997; Bourn and Prescott, 2002; Lester, 2006).

1.2 SENSORY PERCEPTION OF FOOD

1.2.1 THE HUMAN SENSES

The sensory properties of a food product are perceived when each of the human sensory receptor organs interact with the physicochemical properties of the food (Kemp *et al.*, 2009). Although, flavour is initially influenced by the receptors in the eyes, nose, tongue and mouth lining, it is the brain which interprets the overall sensation occurring in the mouth (Taylor and Hort, 2004).

1.2.1.1 THE SENSE OF SIGHT

The appearance of any object is determined by the sense of vision as described by Kemp *et al.* (2009). Light reflected by an object enters the lens of the eye and falls on the retina. Receptor cells in the retina convert this light energy into neural impulses that travel to the brain via the optic nerve (Fig. 1.1).

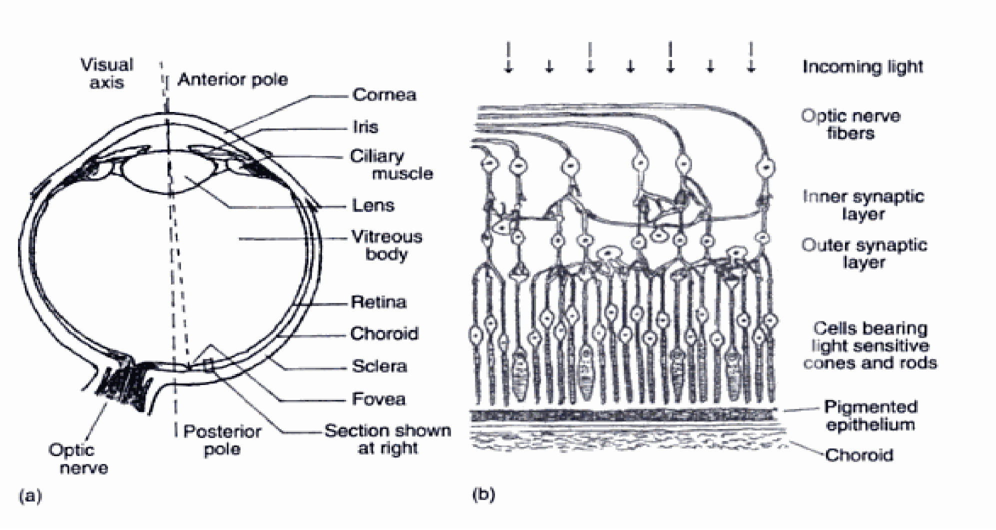


Fig. 1.1: Cross section of the human eye, showing the lens, retina and the optic nerve (Hochberger, 1964).

The brain interprets these signals and perceives the appearance (colour, shape, size, translucency and surface texture) of the object (Meilgaard *et al*., 2007). Perception occurs following the impact of the wavelengths of light in the visible spectrum reflected by the object on the human retina (Francis, 1995). The visible spectrum spans wavelengths of light 390 nm-760 nm (Taylor and Hort, 2004). This means that if an object reflects mainly short wavelengths, it appears blue, in the case of long wavelengths it appears red but if it reflects a mixture of long and medium wavelengths it appears yellow. Individuals do not describe colour in terms of its wavelength, but rather in terms of its hue, its lightness and its saturation (O'Sullivan *et al*., 2003). In addition to this, colour perception is affected by properties of the light source (distance, angle, colour, temperature), as well as background colour, viewing angle and size (Hutchings, 1999; Verhagen and Engelen, 2006). In the literature, sensory evaluation of colour tends to be limited to hue, although some studies include additional measurements of lightness and/or brightness (Montouto-Graña *et al*., 2002; Stommel *et al*., 2005; Treyo Araya *et al*., 2009). In addition to this, several authors have documented that visual stimuli can have a significant effect on flavour identification and appreciation (DuBose *et al*., 1980; Zellner and Durlach, 2003; Shankar *et al.,* 2010)

1.2.1.2 THE SENSE OF TOUCH

The sense of touch is divided into three different groups, those being somesthesis, kinesthesis and chemesthesis (Kemp *et al*., 2009). The skin and mouth contain many different tactile receptors, which are responsible for the somesthetic sensation such as force and particle size (Meilgaard *et al*., 2007). Nerve fibres in muscles, tendons and joints sense tension and relaxation kinaesthetically, giving rise to the perception of the sensory attributes of hardness and heaviness (Kemp *et al*., 2009). While, chemesthesis is the chemical sensitivity of the skin and mucous membranes, allowing for the perception of hot, burning, tingling, cooling or astringent sensations (Green, 2004).

Although, some texture assessments are performed visually, the main evaluation occurs in the mouth (Cook *et al.*, 2005; Van Vliet *et al.,* 2009). Texture perceived in the mouth is dependent on the behaviour of food when it is fragmented and manipulated by the mouth, tongue and palate during mastication (Lenfant *et al.,* 2009). Mastication has two important functions, to break up food particles small enough so they are well mixed by the saliva to form a coherent bolus that can be swallowed safely (Alexander, 1998), and to enhance flavour release from food matrices (Chen, 2009). Therefore, mastication is not only a process of texture appreciation, but also a process of the full appreciation of taste and flavour.

1.2.1.3 THE SENSE OF SOUND

The sense of sound may not often be considered an important aspect of food, but it can play an important role in influencing acceptance of a product. Sound is sensed by millions of tiny hair cells in the ear (Fig. 1.2) that are stimulated by the vibrations from sound waves (Kemp *et al*., 2009). The vibrations are sent via the small bones in the middle ear to create hydraulic motion in the fluid of the inner ear, the cochlea, which is a spiral canal covered in hair cells that, when agitated, sends neural impulses to the brain (Murray and Richmond, 2001).

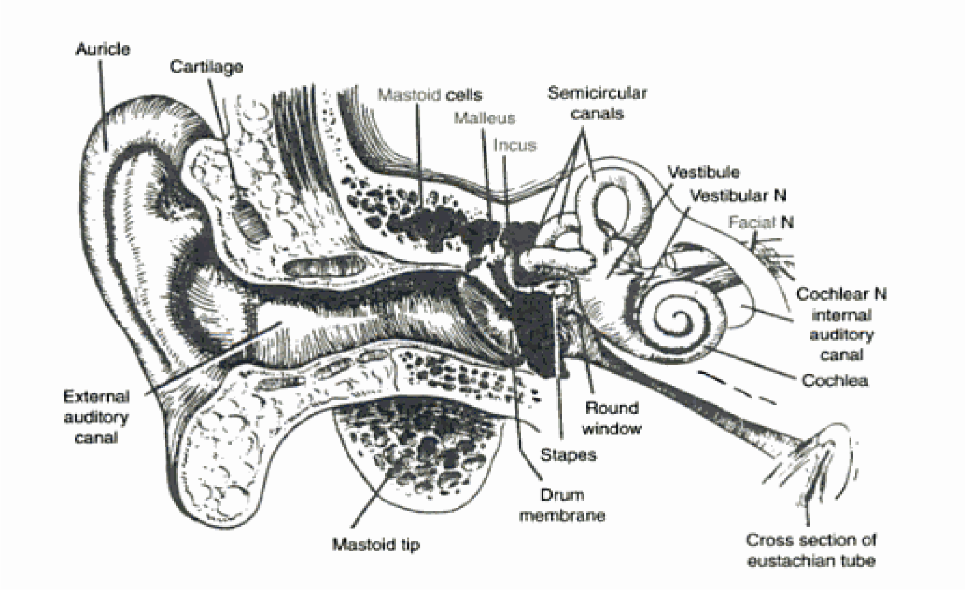


Fig. 1.2: Cross section of the human ear (Kling and Riggs, 1971).

The noise emitted by a food during chewing or biting gives an indication of the texture of the product, e.g. the crispness of a lettuce leaf, the crunchiness of an apple (Verhagen and Engelen, 2006). The influence of sound on the perception of flavour has focused on the textural attributes, namely crispness (Péneau *et al.,* 2006). In order for crispness to be perceived it requires multiple fracture events accompanied by acoustic emissions (Van Vliet *et al.,* 2009) Acoustic emissions require a crack speed of ~300-500m/s for foods to be perceived as crispy (Luyten and Van Vliet, 2006). Individuals can only distinguish sound impulses when the time interval between pulses is at 3-5 ms (Hartman, 1997).

1.2.1.4 THE SENSE OF SMELL

The sense of smell is one of the chemical senses which is critical for the evaluation of foodstuffs (Delwiche, 2004). When a food is taken into the mouth, volatile compounds are released and travel to the olfactory receptors. Aroma can be sensed orthonasally (i.e. sniffed through the nostrils), or aroma compounds can reach the olfactory receptors via the throat after the mastication process, retronasally (Taylor and Hort, 2004).

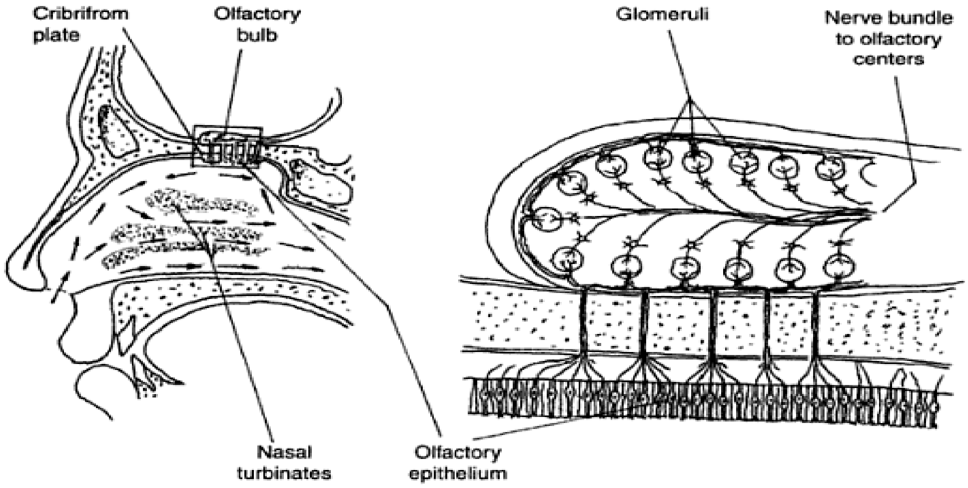


Fig. 1.3: Anatomy of the olfactory system (Axel, 1995).

Aromas are sensed in the olfactory epithelium which is situated in the olfactory bulb in the roof of the nasal cavity (Fig. 1.3). The olfactory epithelium covers a series of protrusions, called turbinates, in the lateral walls of the nasal cavity (Reinceccius, 2006). Most of the olfactory epithelium is found in the olfactory cleft, which is linked to the olfactory bulb of the brain by the cribriform plate (Pernollet and Briand, 2004). When air is brought into the nose during eating, odour compounds are sensed by the olfactory neurons which cover the olfactory epithelium (Hornung, 2006). The olfactory neurons have a single dendrite going to the central nervous system and a dendrite that terminates on the body surface (i.e. the olfactory epithelium). Each of these olfactory neurons lie in the thin layer of mucus. Aroma molecules passing up through the nasal concha dissolve in the mucous lining, where they are detected by the dendrites (Reinceccius, 2006).

Mastication significantly changes the food in terms of surface area, hydration and time in the mouth, which in turn affects the transportation of aroma compounds from food to the gas phase in the mouth, to the olfactory receptors in the nose (Van Ruth and Roozen, 2002). Food composition also affects aroma release as aroma compounds maybe dissolved, absorbed, bound entrapped, encapsulated or diffusion limited by food components (Van Ruth *et al.*, 2000). The aroma stimulus depends upon the concentration of aroma compounds in the nasopharynx, which in turn, is affected by the release rates of compounds from the food in the mouth.

1.2.1.5 THE SENSE OF TASTE

During consumption, food is first brought into the mouth and subsequently processed in the oral cavity. The velum separates the oral cavity from the pharynx during mastication and separates the nasal cavity from the pharynx during swallowing. While, the epiglottis separates the oesophagus from the trachea (Chen, 2009). The teeth are the main agents for chewing and mastication. Biting force varies between teeth. For example, the incisors apply the smallest amount of force (≤ 150N), the canines apply a moderate force (≤300N), while the molars are capable of applying a force of 500N or more (Mioche and Peyron, 1995).

The geometry of a food also affects biting behaviour. Peyron *et al.*, (1997) found that human perception of hardness from the first bite increased with sample thickness. The tongue plays an important role throughout the whole oral processing of food. It not only works as a major sensory organ to sense temperature and texture, and to act as a mechanical device for food manipulation, but also allows individuals to taste food. The taste sensations of sweetness, sourness, bitterness, saltiness and umami are detected by taste buds located in the oral cavity. These taste buds are found on the surface of the tongue in papillae (Fig. 1.4). There are four types of papillae, namely fungiform, filliform, foliate and circumvallate papillae (Meillgaard *et al*., 2007).

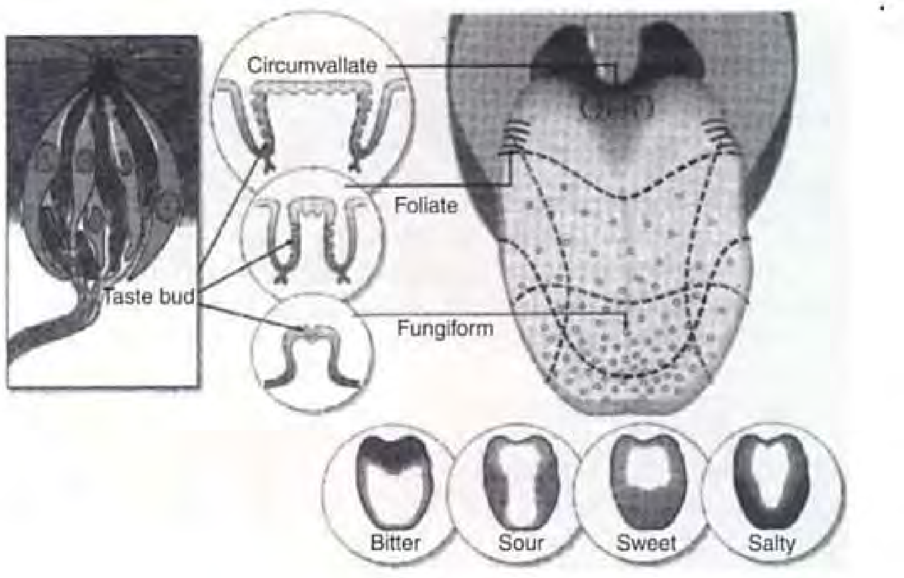


Fig. 1.4: Anatomy of the tongue highlighting the taste buds and regions of sensitivity (Hoon *et al.,* 1999)

The fungiform papillae are pinkish spots located on the front part of the tongue containing one or more taste buds. While the middle section of the tongue is entirely covered with fillifom papillae. At the back of the tongue, there are 12 larger taste buds containing circumvallate papillae. Taste buds are also located in the foliate papillae, which are on the sides of the rear of the tongue. Each cell contains more than one type of receptor. When tastants are dissolved in saliva and contact the taste cells through the taste pores, they interact with taste receptors on the surface of the cells (Rawson and Li, 2004). These interactions cause electrical changes in the taste cells, which prompt them to send chemical signals from the chorda tympani nerve (anterior tongue) or the glossopharyngeal nerve to the brain (Smith and Margolskee, 2001). The surface of the oral cavity is covered with saliva. According to Van Vliet *et al.* (2009) is saliva comprised primarily of water (~99.5%), proteins (0.3%) and inorganic compounds (0.2%). Saliva is secreted into the mouth by three major glands and functions in digestion, dentition protection, mucosal protection and protection through pH maintenance (Van Ruth and Roozen, 2000). Secretion of saliva from the salivary glands is under both sympathetic and parasympathetic control The latter has control over the volume of saliva produced, whereas the former has greater control over certain proteins released (Beidler, 1995).

1.2.2 FLAVOUR

The senses, although generally studied in isolation, do not operate independently (Koza *et al.*, 2005). Flavour has been defined as an amalgamation of olfactory, gustatory and trigeminal sensations perceived during eating and drinking (ISO, 1992).

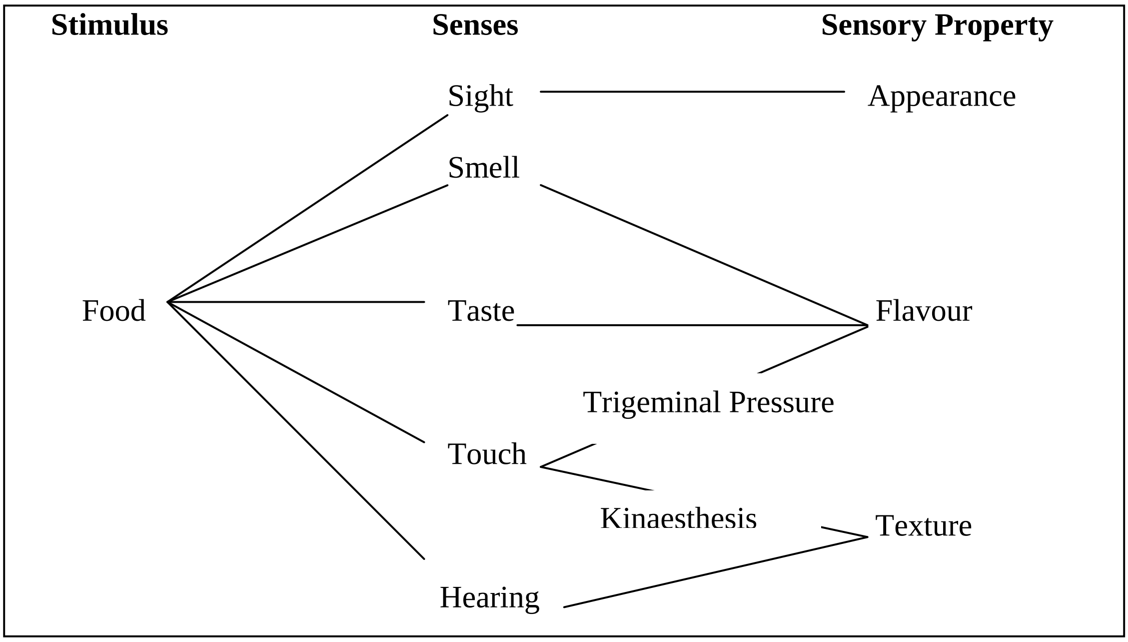


Fig. 1.5: Relationship of the five senses with sensory properties (adapted from Fisher and Scott, 1997).

The simple notion that flavour is the result of well known taste and aroma stimuli has been replaced by the realization that it is a multi modal phenomenon (Fig. 1.5).

A complete flavour experience depends on the combined responses of our senses and cognitive processing of these inputs (Reineccius, 2006). For instance, the discoloration of chocolate due to surface fat crystallisation causes little change to the aroma, taste or mouthfeel modalities, but reduces the enjoyment through visual stimulus. Similarly, distinctive crisp crunchy sounds are emitted when fresh fruit and vegetables are bitten, but when the sounds are not as expected, the expectations of freshness and acceptability will be reduced (Szymczak *et al*., 2007).

Other cross-modal findings to emerge from flavour research are the effect of odours to elicit changes in the perceived sweetness of food stuffs (Stevenson *et al*., 1999) and the influence of texture on the odour of a food product (Pangborn and Szczesniak, 1973).

1.2.3 FLAVOUR PERCEPTION

Flavour perception involves the senses of sight, smell, taste, touch and sound (Fisher and Scott, 1997). It is important to note that vision and (orthonasal) olfaction provide somewhat of a unique contribution to flavour perception in that they typically give us information prior to our consumption of food and drink.

This contrasts with the more proximal senses of taste, touch, audition and retronasal olfaction that normally only provide flavour information once the food or drink item has entered the mouth.

The perception of the flavour emerges from the integration of information provided by the multisensory inputs (Verhagen and Engelen, 2006; Bult *et al.*, 2007; Auvray and Spence, 2008; Shankar *et al.*, 2010).

Figure 1.6 illustrates the different factors that affect flavour perception.

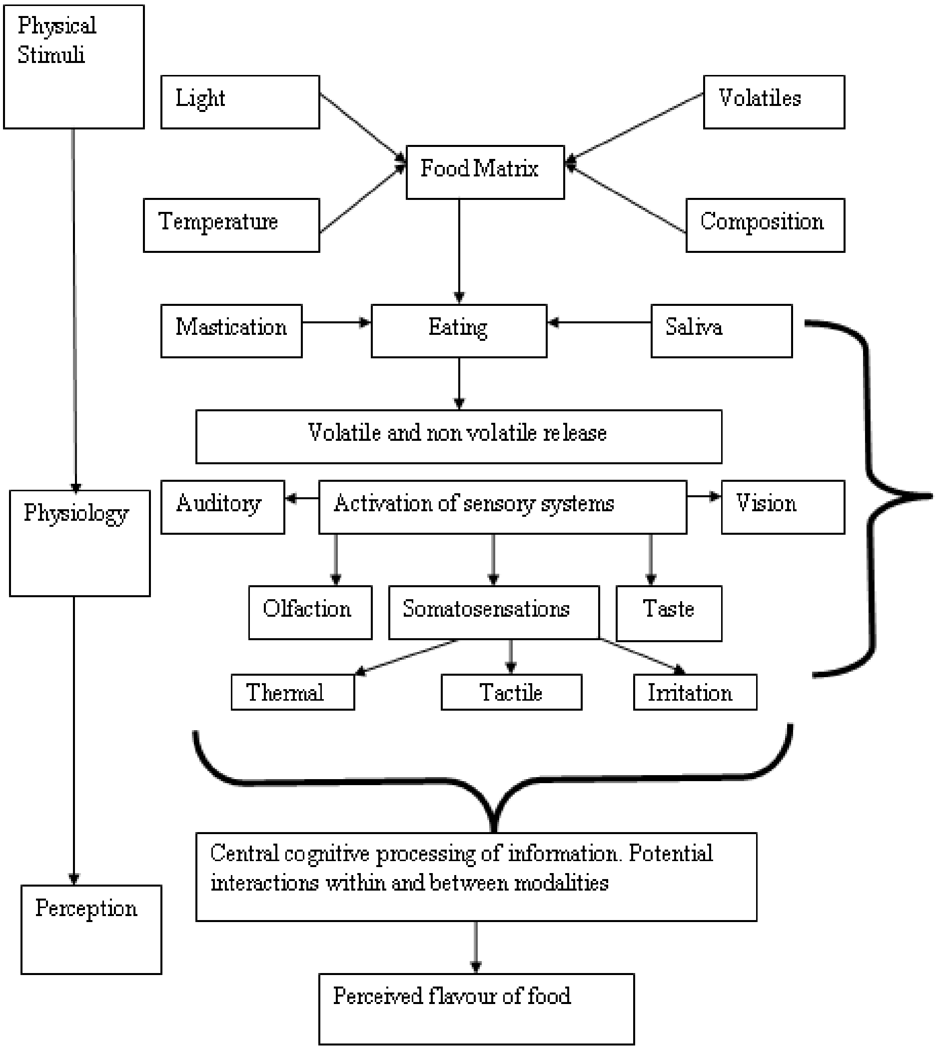


Fig. 1.6: Flow diagram outlining the various stages and factors that influence flavour perception (adapted from Keast *et al*., 2004).

The perception of flavour comprises the combination and interaction of odours, tastes, oral irritations, thermal sensations and mouth feel attributes that arise from a particular food (Breslin, 2001). The physicochemical properties of a food product activate a large variety of receptors within each sensory modality. On the activation of each sensory system, chemical messages, which are converted to electrical signals, are sent to specific regions of the brain via the afferent nerves. The brain decodes these signals in both the specialized areas of the brain and areas common to the different sensory modalities. Flavour is therefore perceived as a result of a series of complex chemical interactions between food, the human senses, and perceptual and cognitive processes during eating and drinking (Keast *et al*., 2004).

1.2.3.1 INTERACTIONS OF COLOUR, TASTE AND AROMA

Colour forms a central part of the experience of food, because of its role as an indicator of edibility, and its role in suggesting both the likely identity and intensity of flavour (Zampini *et al.,* 2007; Zampini *et al.,* 2008; Shankar *et al.,* 2010). Many studies have revealed a significant effect of colour on the perception of sweetness (Johnson and Clydesdale, 1982; Zellner and Durlach, 2003) and the identification of flavours (DuBose *et al.,* 1980; Zampini *et al.,* 2008; Shankar *et al.,* 2010). By contrast, researchers have reported that the addition of colour has far less of an effect on the perceived saltiness of foods such as soup, perhaps because there are no particular colours associated with the salt content of a food (Maga, 1974). Research also indicates that colour has a strong influence on the qualitative determination of odours (Zellner and Whitten, 1999; Morrot *et al*., 2001). In a study conducted by Koza *et al.,* (2005), it was reported that when aromas were smelled orthonasally, colour enhanced the odour intensity scores.

In a study by Davidson *et al*. (1999), participants had to continuously rate the perceived intensity of flavour in their mouths while chewing a piece of mint flavoured gum. The result of the study showed that people's perception of the intensity of the menthol flavour was actually being driven by the release of sugar in their mouths.

1.2.3.2 INTERACTIONS OF TEXTURE, AROMA AND TASTE

Another interesting finding to emerge from flavour research is the influence of texture on the aroma of a food product. Increasing viscosity was consistently found to reduce odour intensity (Pangborn and Szczesniak, 1974). In the aforementioned study, this effect was interpreted solely in thermodynamic terms resulting from the lower volatile mobility at the food-air-interface. Nonetheless, more recent scientific studies suggest that these interactions occur in the central nervous system since aroma suppression by increased viscosities also occurs when nasal volatile concentrations remain unaffected (Hollowood *et al.,* 2002; Visschers *et al.,* 2006). Research studies also suggest that somatosensory tactile stimuli can interact with taste and aroma altering their perception. For example, increasing levels of taste stimuli (sucrose, citric acid or sodium chloride) has been shown to decrease the perceived viscosities of a solution and can lead to a decrease in both taste and flavour intensity ratings (Cook *et al.,* 2005). Christensen (1980a; 1980b) has demonstrated that changes in the viscosity of a solution can modify its perceived taste and flavour and vice versa.

1.2.3.3 INTERACTIONS OF SOUND AND TEXTURE

The perception of the pleasantness of a food is influenced not only by its look, smell and taste, but also by its oral texture and by the sound that it makes in the mouth when we eat it. (Duizer, 2001). The influence of audition on the perception of food has mainly been focused on the textural properties of food, showing for example, that the perceived crispiness and crackliness of food varies with the auditory cues presented (Vickers, 1984; Delwiche, 2004). Zampini and Spence (2004) showed that the perception of crispness and staleness of potato chips increased in loudness (>2kHz) during biting action.

1.2.3.4 INTERACTIONS OF SOMATOSENSATIONS, TASTE AND AROMA

The trigeminal system provides information concerning chemical irritation as well as information concerning temperature, texture and consistency of food and all of these sources of information influence the overall perception of flavour that is experienced (Van Ruth and Roozen, 2000). It is thought that odours become more intense as a given sample is heated (Voirol and Dagnet, 1989). Panellist’s assessment of tomato sauce may miss subtle odour off-flavours if it is presented cold, and the balance of sweetness, sourness and fruitiness may appear different for a juice served at room temperature compared to one that is served at 4^{o}C (Delwiche, 2004).

With regards to irritation, gustatory stimuli such as salt and citric acid (when presented at a sufficiently high concentration) can have irritant qualities (Prescott *et al.*, 1993). Similarly olfactory compounds such as butyl acetate (which has a fruity odour) can elicit activity in the trigeminal nerve (Cain, 1974). Reciprocally, some irritants such as capsaicin have been shown to inhibit the perceived sweetness of sucrose of tomato soup (Prescott and

Stevenson, 1995). Many aroma compounds that stimulate olfactory neurons are also capable of stimulating nasal irritation, i.e. benzaldehyde and iso-amyl acetate (Keast *et al.*, 2004). The perception of taste may also be influenced by suprathreshold odours. Frank *et al.* (1989) showed that strawberry aroma enhanced the perception of sweetness in sucrose solutions, while Hornung and Enns (1994) reported that as the intensity rating for ethyl butyrate increased, so did the perception of sweetness. When aromas possess a taste quality such as sweetness, it can be difficult for an assessor to distinguish between both the aroma and taste properties of the product (Prescott, 1999).

1.2.3.5 COGNITIVE PRECONCEPTIONS AND FLAVOUR PERCEPTION

Many experiments have shown that information about a product may influence hedonic and analytical sensory judgements. For example, a label indicating that soy was in a nutrition bar negatively influenced the sensory evaluation of that bar, which in fact did not contain soy (Wansink and Park, 2002). Caporale and Monteleone (2004) reported that consumer liking of a beer was influenced by the method of production. While, the origin of a wine influenced wine ratings as observed by Wansink *et al.* (2007). Hedonic rating of green tea differed when feminine information about the tea was given compared with masculine information (Hirokawa and Yamazawa (2008). A study by Siegrist and Cousin (2009) showed that negative information about wine resulted in lower sensory scores compared to a group that received positive information prior to testing. In the same study no such effect was observed when the panel received information after tasting.

Information on organic flour origin also increased the liking of bread compared to information on the origins of conventional flour (Kihlberg *et al.,* 2005). Furthermore, members of a sensory panel were influenced by product information about organic and conventional tomatoes (Johansson *et al*., 1999) and beetroot, carrot and curly kale (Hansen, 1981).

1.3 VEGETABLE FLAVOUR

1.3.1 VOLATILE COMPONENTS OF RAW AND COOKED VEGETABLES

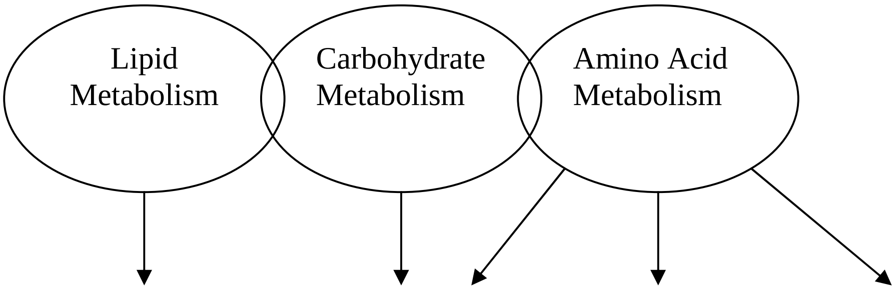
Several factors can affect the volatile profile of vegetables, such as cultivar, stage of maturity, growing conditions and postharvest handling practices (Christensen *et al*., 2007). For instance, changes in the flavour profiles of *Allium* species of vegetable (onions, shallots, leeks, garlic) are very much dependent on the sulphate content of the growth medium (Freeman and Mossadeghi, 1971). Similarly, it has been reported that excessive rainfall often results in large, lush vegetables that lack flavour (Baldwin *et al*., 1995).

Studies conducted on artificially ripened tomatoes and vine ripened tomatoes showed that flavour was significantly reduced in the artificially ripened tomatoes when compared to the vine ripened tomatoes (Maul *et al.*, 1998). Furthermore, it has been documented that many vegetable aroma compounds are only released from raw vegetables when they are processed i.e. peeled, chopped or cooked (Fisher and Scott, 1997). Adams *et al*. (1989) reported that peeling and slicing causes severe tissue disruption, breaking of the protective epidermal layer and the releasing of nutrients, enzymes and volatile compounds. While, Cliffe-Byrnes *et al*. (2007) showed that the more severe the peeling or slicing of carrots was, the more disruption that was caused to the tissue, which in turn resulted in increased respiration rates.

Although some vegetables, such as tomato, carrot, cucumber and onion are consumed in their raw form, it is generally accepted that most vegetables are cooked prior to consumption. It has been reported that many of the aroma compounds found in cooked vegetables are usually the same as those found in raw vegetables, however, quantitative differences frequently occur (Christensen *et al*., 2007).

Additionally, utilising different methods of cookery can result in the synthesis of a new group of volatile compounds (Wang and Kays, 2000).

Fatty acid, carbohydrate, and amino acid metabolism, serve to provide precursors of vegetable aroma (Fig. 1.7).



Non Volatile Precursors			
Linolenic acid Linoleic acid	Thioglucosinolates	Cysteine sulfoxides	Methyl methionine
Precursor Splitting Enzymes			
Lipoxygenase	Thioglucosidases	C-S-Lyases	Non-heating
↓	↓	↓	↓
Carbonyls Alcohols Oxo-acids	Isothiocyanates Nitriles S=C=O Thiocyanates	Polysulfides Alkyl-thiocyanates	Sulfides

Fig. 1.7: The formation of vegetable aroma from major food components (adapted from Tressl *et al.*, 1975).

1.3.1.1 LIPID METABOLISM

Lipids contribute to vegetable aroma mainly through the lipoxygenase (LOX) pathways and the levels found within a plant can vary considerably depending on developmental and environmental conditions (Rosahl, 1996).

Plant lipoxygenases play a part in flavour and odour formation which are very important contributors to vegetable quality. During plant cell breakdown lipoxygenase (LOX) catalyses the oxygenation of linoleic and linolenic acids to form fatty acid hydroperoxides (Reineccius, 2006).

An example of this pathway is depicted in Fig. 1.8.

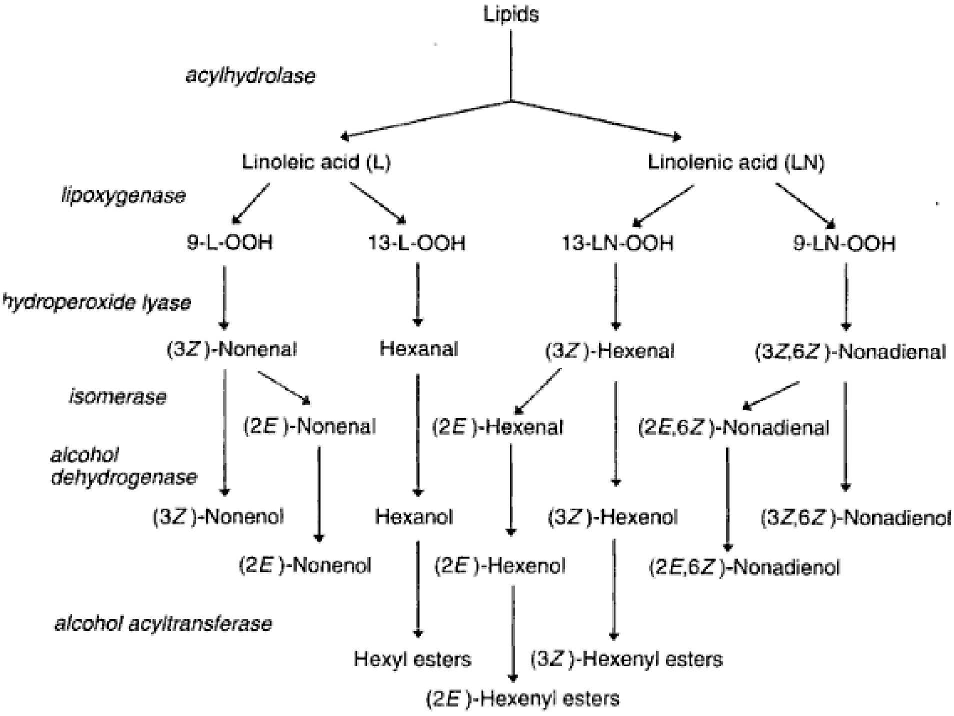


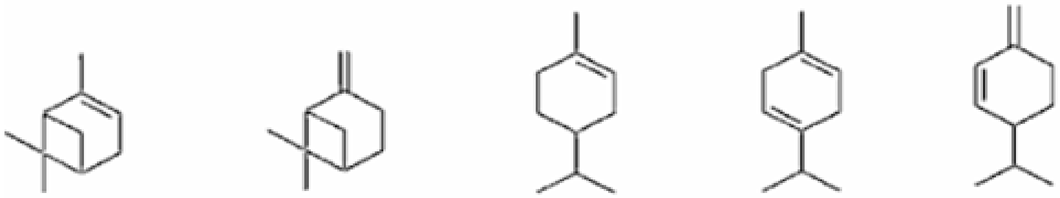
Fig. 1.8: Enzymatic activities and products involved in the LOX pathway (Sanz et *al.*, 1997).

Each vegetable has its own unique set of lipoxygenases. These break down further with the help of other enzymes (hydroperoxides lyases, alcohol dehydrogenases, isomerases and esterases) to form aliphatic esters, alcohols, acids and carbonyl volatiles (Fisher and Scott, 1997). Limited research has been conducted on thermal fatty acid breakdown, but it is thought to involve the decomposition of hydroperoxides in the raw product and/or oxidation of preformed volatile compounds (Christensen *et al*., 2007).

1.3.1.2 CARBOHYDRATE METABOLISM

Only a few groups of aroma compounds found in vegetables derive from carbohydrate metabolism, such as terpenes and furanones (Fisher and Scott, 1997).

Terpenes are considered to arise from both carbohydrate and lipid metabolism via the isoprenoid pathway, while furanones are produced from intermediates of the pentose phosphate cycle (Sanz *et al*., 1997). Terpenes are classified by the number of isoprene units contained in their structure (Fig. 1.9). Monoterpenes contain two isoprene units, sesquiterpenes contain three isoprene units and diterpenes contain four isoprene units (Reineccius, 2006). The majority of volatile components emitted from raw carrots are monoterpenes and sesquiterpenes and have been shown to contribute significantly to the aroma and taste properties of carrots (Kjeldsen *et al*., 2001; Kreutzmann *et al*., 2008).



(a) α-Pinene **(b) β-Pinene** **(c) Terpinolene** **(d) γ-Terpinene** **(e) β-Phellandrene**

Fig. 1.9: Structures of terpenes that occur in vegetables (Christensen *et al.*, 2007).

Christensen *et al*. (2007) reported that cooking results in an increase in the formation of terpene alcohols, whereas Alasalvar *et al*. (1999) documented 88.6%, 93.0% and 95.5% losses in monoterpenes and sesquiterpenes after cooking times of 10, 20 and 30 minutes respectively in cooked carrots. The formation of 2,5-dimethyl-4-hydroxy-2H-furan-3-one is another example of carbohydrate metabolism (Zabetakis *et al.,* 1996). The pathway presented in Fig.1.10 shows the formation of 2,5-dimethyl-4-hydroxy-2H-furan-3-one from its precursor, 6-deoxy-D-fructose.

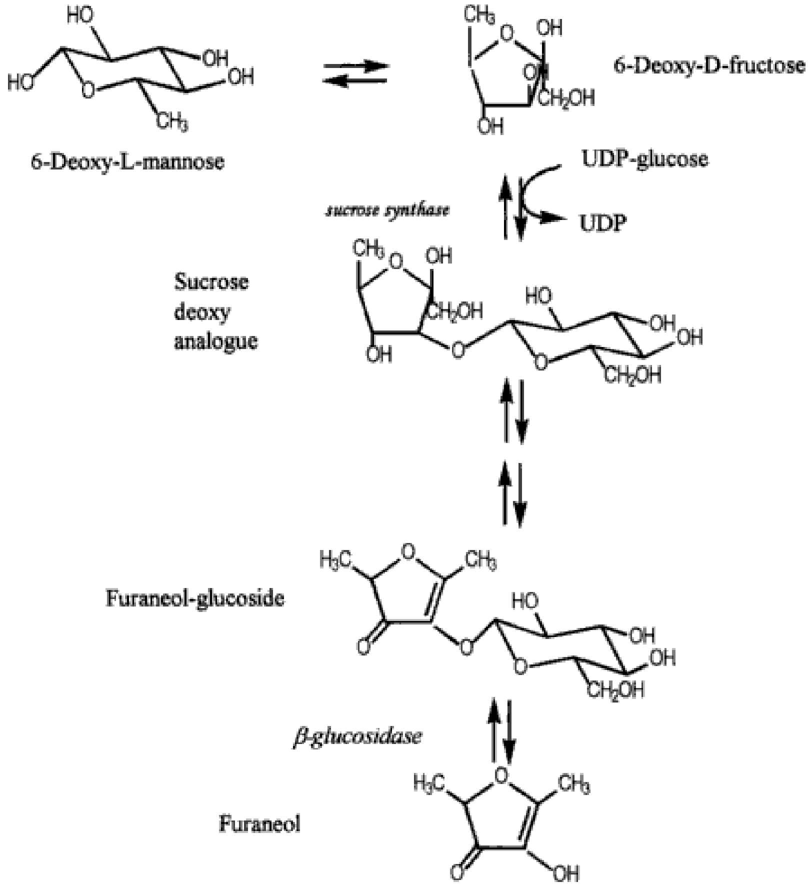
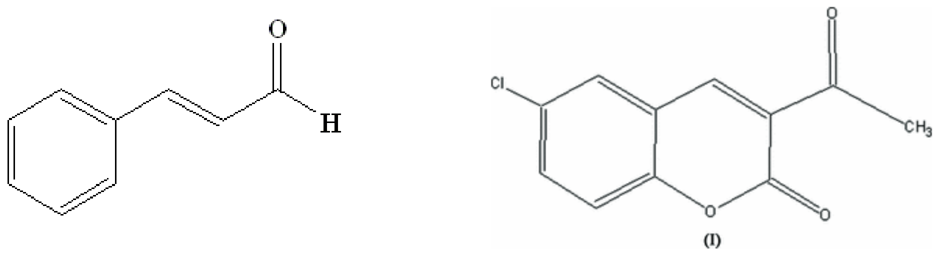


Fig. 1.10: The formation of 2,5-dimethyl-4-hydroxy-2H-furan-3-one (Zabetakis *et al.,* 1996).

The aroma compound 2,5-dimethyl-4-hydroxy-2H-furan-3-one is an important aroma contributor for several fruits and vegetables, for example, pineapples, raspberries and tomatoes (Buttery *et al.,* 1995).

1.3.1.3 AMINO ACID METABOLISM

In amino acid metabolism, enzymes remove both amine and carboxyl groups from the amino acids to produce aromatic, aliphatic and branch chained alcohols, acids, carbonyls and esters (Fisher and Scott, 1997). Yu *et al*. (1968) showed that the amino acids valine, leucine and alanine could be converted to short chain carbonyls in tomato extracts. Additionally, deamination and oxidation of phenylalanine and tyrosine results in the formation of many aromatic compounds, such as cinnamaldehyde and courmarin as depicted in Fig. 1.11 (Beaulieu and Baldwin, 2001).



(a) cinnamaldehyde **(b) coumarin**

Fig. 1.11: Structures of (a) cinnamaldehyde and (b) coumarin (Fisher and Scott, 1997).

Thermal degradation of amino acids is often associated with other food components, such as sugars (Christensen *et al.,* 2007). Volatiles formed as a result of amino acid-sugar interactions include Strecker degradation aldehydes, pyrazines, thiazolines, thiazoles and other heterocyclic compounds (Buttery, 1981; Maarse, 1991).

1.3.1.4 MAILLARD REACTION

The Maillard reaction plays an important role in the development of flavour in cooked vegetables. The Maillard reaction occurs as a result of a reaction between carbonyls and amines. The carbonyls are usually reducing sugars, while the amines are derived from proteins or amino acids.

Approximately 3,500 aroma compounds are reported to have been formed as a result of this reaction (Fig. 1.12), making them particularly important to cooked food aroma (Reineccius, 2006).

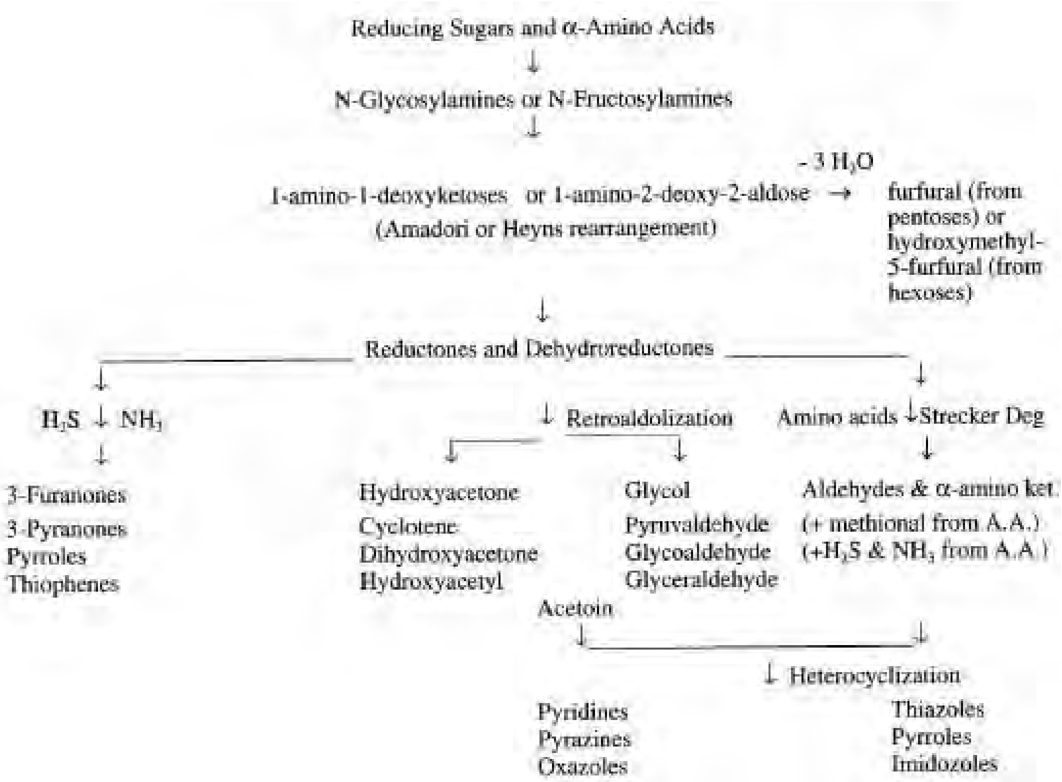


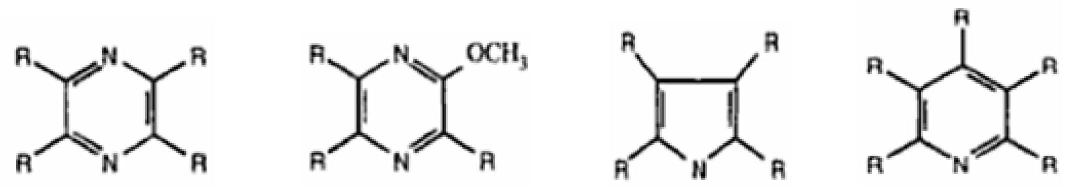
Fig 1.12: Formation of flavour compounds as a result of the Maillard reaction (Vernin and Parkanyi, 1982).

According to Nursten (2005) volatiles that are formed as a result of the Maillard reaction are classified into three groups:

- Simple sugar dehydration/fragmentation products i.e. furans, pyrones, cyclopentenes, carbonyls and acids.
- Simple amino acid degradation products i.e. aldehydes
- Volatile compounds produced by further interactions i.e. pyrroles, pyridines, imidazoles, pyrazines, oxazoles, and thiazoles.

1.3.1.4.1 NITROGEN CONTAINING HETEROCYCLIC VOLATILE COMPONENTS

Nitrogen containing heterocyclic compounds (Fig. 1.13) generally arise from a reaction of proline and hydroxyproline with dicarbonyls via the Strecker degradation pathway (Reineccius, 2006).



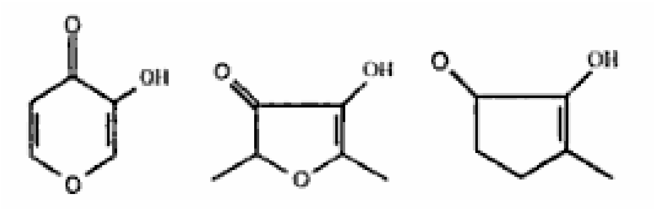
(a) Pyrazine **(b) Methoxypyrazine** **(c) Pyrrole** **(d) Pyridine**

Fig. 1.13: Structures of nitrogen containing heterocyclic volatiles produced via the Maillard reaction (adapted from Reineccius, 2006).

Pyrazines are the most studied nitrogen containing heterocyclic compounds and are usually responsible for roasted or cereal notes (Heath and Reineccius, 1986). However, methoxypyrazines usually impart an earthy vegetable aroma (Allen and Lacey, 1997). According to Maga (1981) pyrroles are also widely found in cooked foods. Typical pyrrole aroma compounds include 2-formyl pyrrole and 2-acetyl pyrrole (Ohloff and Flament, 1979). The aroma compound 2-formyl pyrrole imparts a corn-like odour, while 2-acetyl pyrrole emits a sweet caramel like odour. Pyridines are less widely distributed in cooked foods when compared to pyrazines and pyrroles (Maga, 1981). They emit a wide range of odours, although green notes are very common (Pittet and Hruza, 1974).

1.3.1.4.2 OXYGEN CONTAINING HETEROCYCLIC VOLATILE COMPONENTS

Typical oxygen containing heterocyclic volatile compounds (maltol, furaneol and cyclotene) are illustrated in Fig. 1.14. The characteristic aromas associated with these compounds are caramel, sweet, fruity, butterscotch and burnt. Oxygen containing heterocyclic volatile compounds are formed as a result of the cyclization of non-nitrogen containing browning intermediates (Reineccius, 2006).

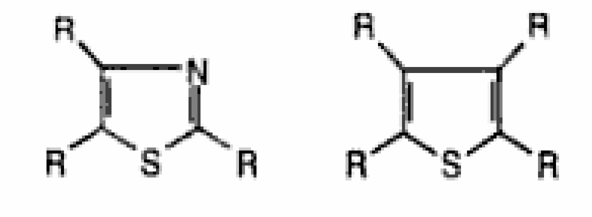


(a) Maltol **(b) Furaneol** **(c) Cyclotene**

Fig. 1.14: Structures of oxygen containing volatiles produced via the Maillard Reaction (Reineccius, 2006).

1.3.1.4.3 SULPHUR CONTAINING HETEROCYCLIC VOLATILE COMPONENTS

The most important sulphur containing heterocyclic volatile compounds are thiophene and thiazole (Fig. 1.15). Sulphur containing heterocyclic compounds are also formed as a result of the Maillard reaction. Thiophenes are strong odorous compounds found in cooked foods (Ohloff and Flament, 1979). Thiazoles and pyrazines have been reported to have similar odour properties (Pittet and Hruza, 1974). The most well known thiazole compound is the aroma volatile 2-isobutyl thiazole (Reineccius, 2006). This compound imparts a green vine aroma and is reported to be an important contributor to tomato flavour (Petro-Turzá, 1987).



(a) Thiazole **(b) Thiophene**

Fig. 1.15: Structures of sulphur containing volatiles produced via the Maillard Reaction (Reineccius, 2006).

1.3.1.5 VOLATILE PROFILES OF ROOT, TUBER AND FRUIT VEGETABLES

1.3.1.5.1 CARROT VOLATILES

Carrot flavour has been assessed by volatile composition (Seifert and Buttery, 1978; Simon *et al.*, 1980; Cliffe-Byrnes and O'Beirne, 2007). Terpenes and sugars found in carrots are the most important sensory indicators of consumer acceptance. Carrot aroma has a complex volatile profile (Heatherbell and Wrolstad, 1971).

The majority of volatile components emitted from raw carrots are monoterpenes and sesquiterpenes and have been shown to account for 98% of the total volatile mass in carrots (Kjeldsen *et al.*, 2001). The aroma volatiles α-pinene, sabiene, β-pinene, γ-terpinene, terpinolene, limonene, β–caryophyllene, humulene, *p*-cymene, (E)- γ-bisabolene are documented to be the key flavour components of raw carrots (Alasalvar *et al.*, 2001; Kjeldsen *et al.*, 2001 and Cliff-Byrnes and O'Beirne., 2007).

1.3.1.5.2 POTATO VOLATILES

For potatoes, intensity of potato aroma, mustiness and earthiness are common descriptors used to describe both cooked and raw potato aroma (Montouto-Graña *et al*., 2002; Hajšlová *et al*., 2005). Raw potatoes have very little aroma especially, when compared to cooked potatoes, however (*E*,*E*)-2,4-decadienal, (*E*,*Z*)-2,6-nonadienal, and (*E*)-2-octenal, which are all by products of LOX initiated reactions of unsaturated fatty acids have been found in freshly cut tubers (Christensen *et al*., 2007). Cooked potato flavours are very dependent on the chosen method of cookery (Coleman *et al*., 1981). Boiled potato aroma volatiles deemed to be important include methional, aliphatic alcohols, aldehydes, sulphides, and methoxypyrazines. (Maga, 1994; Oruna-Concha *et al*., 2002). While, for baked potatoes alkylpyrazines are very important, as are oxazoles, pyrroles, thiazoles, methinonal and aliphatic aldehydes (Coleman *et al*., 1981; Oruna-Concha *et al*., 2002).

1.3.1.5.3 TOMATO VOLATILES

Tomato aroma is particularly important in terms of sensory acceptability. In fact, over 400 aroma compounds have been identified as volatile constituents of tomato and tomato products (Petró-Turza, 1987) and of those, only around 30 are considered to be important contributors to fresh tomato flavour as determined by odour threshold studies (Buttery and Ling, 1993). The most important aroma volatiles are thought to be *cis*-3-hexenal, hexenal, *trans*-2-hexenal, *cis*-3-hexenol, 2-isobutylthiazole, 6-methyl-5-hepten-2-one, β-ionone, geranylacetone, 1-penten-3-one, 3-methylbutanal, 3-methylbutanol, phenylethanol, 2-pentenal, acetone, ethanol and methanol and the main precursors of these volatile compounds are free amino acids, fatty acids and carotenoids (Buttery and Ling, 1993).

Typical descriptors used to describe tomato aroma include vine, green, ripe, earthy, sweet tomato, musty, tropical, floral and overall tomato aroma (Krumbien and Auerswald, 1998; Baldwin *et al*., 2004; Krumbien *et al*., 2004).

1.3.2 NON VOLATILE COMPONENTS OF RAW AND COOKED VEGETABLES

1.3.2.1 SUGARS

Sugar content is a particularly important factor for determining the quality and sensory acceptability of vegetables and has been discussed by several authors (Varming *et al*., 2004; Heeb *et al*., 2005; Heeb *et al*., 2006; Maggio *et al*., 2008). Sugar plays an extremely important role in carrot flavour. The main types of sugar that contribute to sweet carrot taste are sucrose, glucose and fructose (Varming *et al*., 2004). High sensory quality and sweetness have been reported to correlate with sugar content. Whereas, bitter carrots often cause consumer rejection and are one of the primary reasons for low scoring in sensory tests (Alasavar *et al*., 2001). Storey (2007) noted that the main sugars found in potatoes are sucrose (0.4-6.6%), glucose (0.15-1.5%) and fructose (0.15-1.5%). The sugar content at maturity is affected by genetics and a number of agronomic and environmental factors. For instance, it has been suggested that a phosphorus and potassium deficiency may lead to a decrease in starch synthesis and an increase in the content of sugars (Burton, 1989).

For tomatoes, dry matter ranges between 5-8% of the total fresh weight of the tomato, and approximately half of this is made up of sugars (Petró-Turza, 1987). The main types of reducing sugars that contribute to sweetness are glucose and fructose, with fructose playing a major part in the composition of tomato flavour (Azodanlou *et al*., 2003). Sucrose may also be present, but its quantity rarely exceeds 0.1% of the total fresh mass of the tomato (Davies and Kempton, 1975). Other sugars which are occasionally present but in minute quantities are raffinose, arabinose, xylose, galactose, and the sugar alcohol myoinositol (Yilmaz, 2000). In the initial stages of development of the tomato, only a small amount of sugar is present (Petró-Turza, 1987). Fructose and glucose increase and malic acid declines during the development to full colour, while sucrose and citric acids are lower and remain relatively constant during the ripening period (Rubatzky and Yamaguchi, 1997). On ripening, the sugar content of a tomato is between 1.7-4.7% depending on the cultivar. Generally, the amount of fructose greatly exceeds that of glucose (Davies and Kempton, 1975). Additionally, cooking can have a significant effect on the sugar content of vegetable products (Rodríguez-Sevilla *et al.*, 1999). In their study, a significant reduction was documented for soluble sugars, glucose, fructose and sucrose content of cooked carrot, beetroot and turnip. De Belie *et al.* (2002) also reported that the ^{o}Brix readings decreased linearly with cooking time for carrots. This reduction in sugar content was attributable to the leaching of sugars into surrounding cooking water. While, Petró-Turza (1987) reported cooking tomato products results in a reduction of sugar content, but this was dependant on time and temperature factors.

1.3.2.2 ORGANIC ACIDS

Organic acids are widely distributed in vegetables. Citric acid and malic acid are the most common acids found in vegetables, however leafy green vegetables may also contain significant quantities of oxalic acid (Nielsen, 2003). Citric acid and malic acid are responsible for giving a sharp sour taste to apples and tomatoes (Fisher and Scott, 1997).

The pH can be used to measure the acidity value of a vegetable. In fact, most vegetables have a low pH because of their acid content. Carrots and potatoes have a typical pH value ranging from 5.5 to 6.5 (Chen *et al*., 1995; Pardo *et al*., 2000), whereas tomato fruit pH usually ranges between 4.3-4.7 (Rubatzky and Yamaguchi, 1997). The pH value is important not only for flavour reasons, but it also influences the nutritional quality and shelf life of the vegetable.

1.3.2.3 PIGMENTS

Colour is often regarded as an important element of sensory quality, as it is the first parameter the consumer uses to evaluate a vegetable. The colour of a vegetable is determined by the presence of pigments such as chlorophylls, carotenoids and anthocyanins present in the skin and flesh of the vegetable.

Carrots vary greatly in colour depending on the cultivar, and may be white, yellow, purple or orange (Alasalvar *et al*., 2001). The main pigments responsible for carrot colour are β-carotene, α-carotene and xanthophylls. Carotenoids are present in carrots and usually range from trace amounts in white varieties to 370 mg per gram for darker orange fleshed varieties (Eskin, 1989). Colour is also an important quality attribute for potatoes. The skin of the potato is generally light yellow, yellow, red or violet in colour (Linińska and Leszczyński, 1989). Yellow skinned varieties obtain their colour from carotenoids, while anthocyanins are responsible for the red, blue and purple coloured skins of the potato (Reyes *et al*., 2004). The flesh of potatoes maybe white, cream or yellow due to the presence of xanthophyll carotenoids (Storey, 2007). Carotenoids are present in the flesh of all potatoes, and carotene content usually range from 50-100 μg per 100 g fresh weight for white fleshed varieties to 2,000 μg per 100 g fresh weight for dark yellow fleshed varieties (Brown, 2005). The colour of the tomato is determined by skin and flesh pigmentation (Brandt *et al*., 2006). The skin colour ranges from colourless to yellow, while the interior flesh colour ranges from green to dark red (Atherton and Rudich, 1986). The red colour of the ripe tomato fruit is due to the degradation of chlorophyll, as well as the synthesis of lycopene and other carotenoids (Fraser *et al*., 1994). In red fruit, the ratio of lycopene to β-carotene, and the concentration of these carotenoids determine the hue and the intensity of the fruit colour (Stommel *et al*., 2005). Cooking can also have a significant effect on the colour of vegetables. For instance, the Maillard reaction not only influences the aroma composition of a food product, but also colour formation. Melanoidins are formed as a result of a reaction between an amino group (amino acids, peptides or proteins) and a glycosidic hydroxyl group (sugars). Melanoidins form as a result of baking, roasting or frying potatoes, and are considered a desirable property associated with the Maillard reaction. Carotenoids are oil soluble and cooking has little effect on them unless at high temperatures. Hutchings (1999) reported that there is a 24% reduction in the carotenoid content of food products when the temperature is increased from 40°C to 100°C. Additionally, lipoxygenase was reported to be responsible for a significant loss of carotenoids in cooked peas (Rhee and Watts, 1966). However, carrots possess only small amounts of lipoxygenase, which means colour changes are often small (Edwards and Lee, 1986).

1.4 ORGANIC FOOD PRODUCTION

1.4.1 DEFINITION OF ORGANIC AGRICULTURE

Organic agriculture is defined as a system of farming that avoids or largely excludes the use of synthetic fertilisers, herbicides, insecticides, fungicides, or any other pesticides, growth hormones or growth regulators (Codex Alimentarius Commission, 2001). Instead the organic agricultural system relies on crop rotations, organic manures and biological pest control, to maintain soil productivity, supply plant nutrients, and control insects, weeds and other pests (Walshe *et al.*, 2006).

1.4.2 WORLDWIDE ORGANIC FOOD MARKET

Global sales of organic produce reached €33 billion in 2007 (Sahota, 2009). The total land managed organically represents almost 1% of the total agricultural land worldwide (Willer *et al.*, 2009). The regions with the largest percentage of organically managed land (Table 1.1) are Oceania, Europe and Latin America (FiBL/IFOAM, 2009).

Table 1.1: Organic agricultural land and producers by region in 2007 (adapted from FiBL/IFOAM, 2009)

	Organically managed agricultural land (ha)	Share of total agricultural land (%)	Producers
Africa	870,329	0.1	529,986
Asia	2,881,745	0.2	234,147
Europe	7,758,526	1.9	213,297
Latin America	6,402,875	1.0	222,599
North America	2,197,077	0.6	12,275
Oceania	12,110,758	2.6	7,222
Total	**32,221,311**	**0.8**	**1,219,526**

Australia, Argentina and Brazil are the countries with the largest organically managed land areas (Table 1.1). Almost half of the world’s organic producers are in Africa. While, the countries with the highest number of organic producers are Uganda, India and Ethiopia (Willer *et al.*, 2009).

1.4.3 EUROPEAN ORGANIC FOOD MARKET

In Europe, the demand for organically farmed food has grown considerably (Fig 1.16), with almost 7.8 million hectares managed organically in 2007, compared to just 0.1 million hectares in 1985 (Willer, 2009).

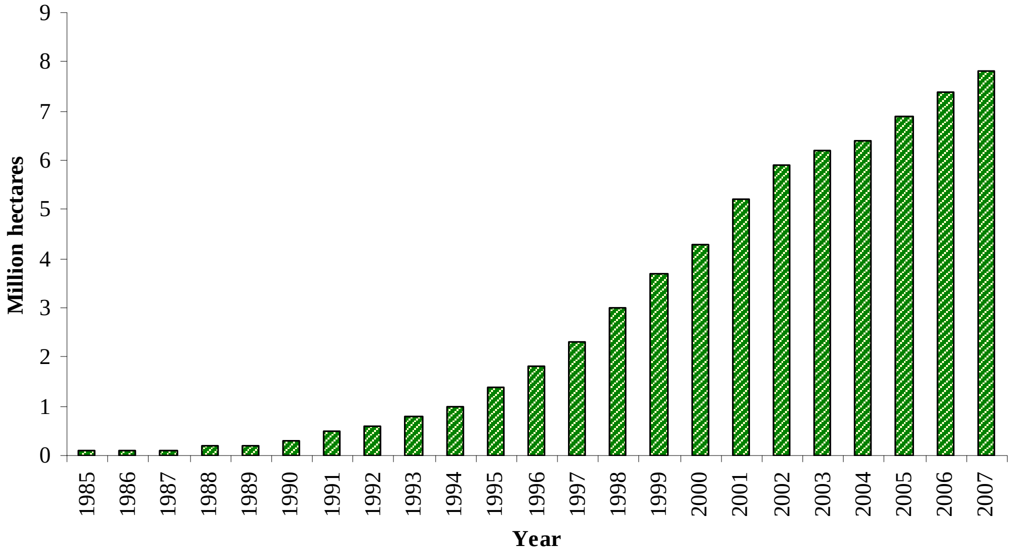


Fig. 1.16: Development of organically managed agricultural land area in Europe, 1985-2007 (adapted from FiBL/IFOAM, 2009)

Approximately 81% of the organic agricultural land in Europe is used for grassland and arable crops (Willer, 2009). While, Schaack (2009) reported that approximately 100,000 hectares of land is used for organic fruit and vegetable production throughout the EU. Europe has the largest market for organic produce in the world, with an estimated value of almost €19 billion in 2007 (Sahota, 2009). The largest organic markets in Europe are in

Germany, the United Kingdom and France (Padel *et al.*, 2009). Scandinavian and Alpine consumers are the biggest spenders on organic food, with organic products now representing over 5% of the total food sales in Austria and Denmark (Sahota, 2009).

1.4.4 IRISH ORGANIC FOOD MARKET

Organically farmed foods have seen a significant rise in popularity in Ireland in recent years (MacConnell, 2008). The market for organic food in Ireland was worth €124 million in 2009, which compares to just €57 million in 2006 (Bord Bia, 2008a; Bord Bia, 2009a). Despite this unprecedented growth, Ireland is currently going through an economic recession. The organic food industry is not only affected by dwindling investments, but declining consumer spending power. It was reported that on average one in every three consumers are spending less on grocery commodities in 2009 than they did 2008 (National Consumer Agency of Ireland, 2010). Consumers who were content paying premium prices of up to 25% for food because it was organic are now finding price differences of more than 10% too expensive (Pope, 2009). Approximately 70% of all organic produce consumed in Ireland is imported, which means only 30% of the produce consumed is produced domestically (Bord Bia, 2007). Additionally Cowan *et al*. (2005) reported that consumers mostly purchased organic produce from supermarkets, but some also purchase organic produce from direct sales with farmers and growers. In Ireland, fruit and vegetable sales contribute very significantly to the value of the organic food market. Bord Bia (2008b) indicated that vegetables were one of the most important organic market segments in 2007 and 2008.

1.4.5 CERTIFICATION OF ORGANIC FOOD IN IRELAND

In order to sell organic produce in Ireland, it must be certified as such. Certified organic food products must be produced according to the guidelines specified in EU law (Council Regulation (EC) No.834/2007, Commission Regulation (EC) 889/2008). There are currently two certification bodies in Ireland, namely, The Irish Organic Farmers and Growers Association and The Organic Trust. These certification bodies are approved by the Department of Agriculture, Fisheries and Food (DAFF) to carry out inspections and certify organic produce. In Ireland, the labelling must include the code number of the inspection authority or the body to which the operator is subject, the producers name, address and/or license number, the appropriate organic logo (Fig. 1.17) and/or the name of the relevant certifying body and the words certified organic.

Fig. 1.17: Logos to identify organic certification bodies in Ireland

In addition, organic food producers are required to register with the Department of Agriculture and Food.

1.4.6 CONSUMER PERCEPTIONS OF ORGANICALLY FARMED FOODS

Organically farmed foods have seen a significant rise in popularity over the past decade. This demand has been fuelled as a result of food safety, highly publicized food scares, an increased consumer awareness of the link between health and diet and the perceived benefits of organically farmed foods (Lester, 2006). The popularity of organic food may also be attributed to the strong reassurances provided by its producers, regarding how the products have been produced.

One of the main drivers for the purchasing of organic vegetables is the differentiation between organic and conventional vegetables with respect to pesticide use and perceived pesticide residues However, it is important to note that pesticide residue levels authorised in conventional farming are very low, and most often below the minimum detection limit (Kumpulainen, 2001; Magkos *et al.*, 2006). The increased number of high profile food scares witnessed in the past decade (Dioxins, Foot and Mouth disease, B.S.E) has also has led to a strong rise in consumer demand for organic produce.

Proponents of organically farmed food also believe it is more nutritious than conventionally farmed food. However, in a study conducted by Dangour *et al.* (2009) it was reported that there is very little difference in the nutritional content of organic food compared to conventional produce. While, Lairon (2009) disagreed, stating organic food contains more dry matter, nutrients (Fe and Mg) and antioxidant micronutrients.

In general, consumers believe organic food to be healthier, tastier, safer and more environmentally friendly than conventionally produced food (Bourn and Prescott, 2002; Bord Bia, 2003; Magkos *et al.*, 2006; Winter and Davis, 2006).

In Ireland the main perceived benefits (Fig. 1.18) given for choosing to purchase organic food included the perception that organic food is healthier, does not contain added chemicals or pesticides, is more natural and tastier than conventional produce (Cowan *et al.*, 2005; Bord Bia, 2008b).

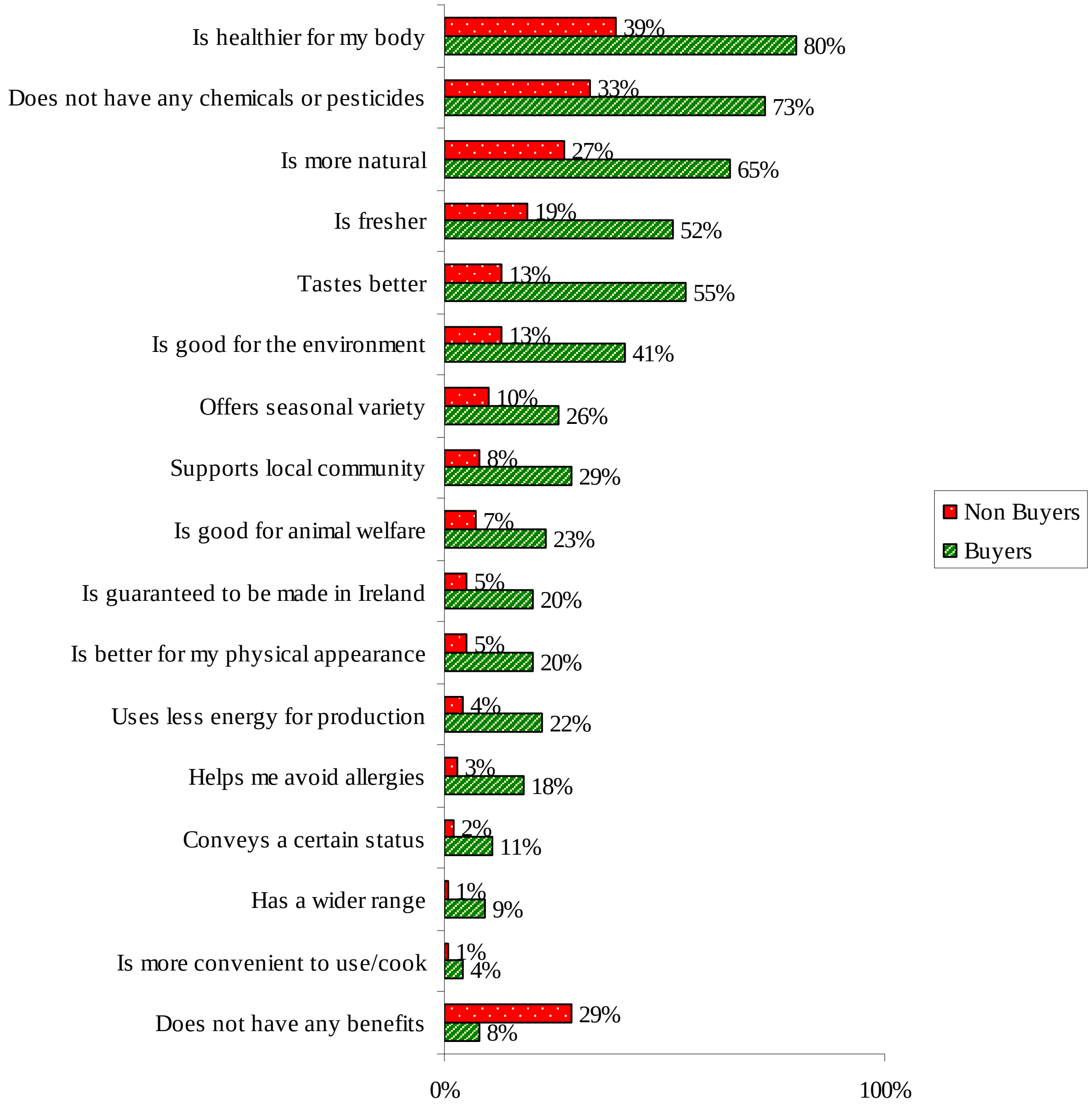


Fig. 1.18: The perceived benefits of buying organic food (adapted from Bord Bia, 2008b).

Additionally, Radman (2005) found that Croatian consumers perceived organically farmed produce as healthier and tastier than conventionally produced foods. While, Makatouni (2002) found that British consumers purchased organic produce for health and taste reasons. According to a survey conducted by Bord Bia (2008b) the principle barrier to purchasing organic produce in Ireland is price (Fig. 1.19). Irish consumers are not the only consumers to consider organically farmed food as expensive. Several other authors reported that price was a significant deterrent to buying organic food (Tregear *et al.*, 1994; Padel and Foster, 2005; Roitner-Schobesberger *et al.*, 2008).

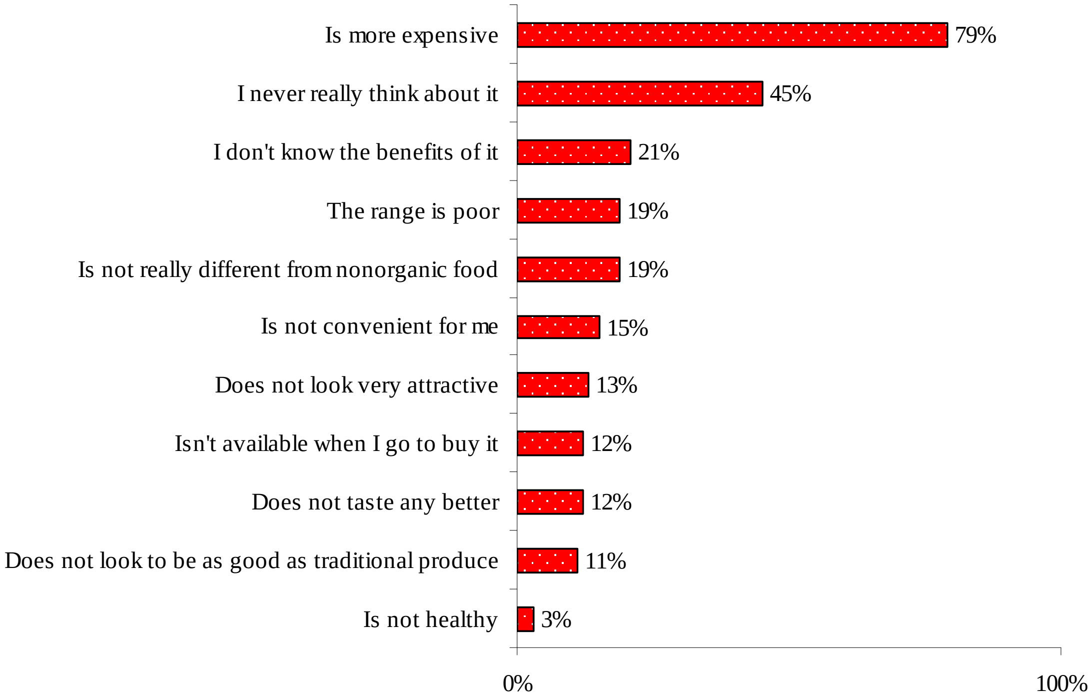


Fig. 1.19: Barriers to the purchase of organic food for non organic buyers (adapted from Bord Bia, 2008b).

Most organically produced foods are more expensive than their conventionally produced counterparts. Cowan *et al.* (2005) found that price premiums ranged between ten and two hundred percent. Consumers generally accept this as the cost of producing organically farmed foods is generally higher than that of food produced from conventional systems (Angood *et al.*, 2008).

1.5 ORGANIC AND CONVENTIONAL VEGETABLE PRODUCTION

1.5.1 ORGANIC VEGETABLE PRODUCTION

In 2008, there were 1,450 registered organic producers in Ireland (Department of Agriculture Fisheries and Food, 2009), which compares to just 583 registered organic producers in 1997 (Teagasc, 2007a). Approximately, 44,751 hectares of land in Ireland is managed organically, of which only 1.5% is used for tillage (Department of Agriculture Fisheries and Food, 2009). Nonetheless, organic vegetables comprised the largest segment of the organic food market in Ireland in 2008 (Bord Bia, 2008b). According to the last organic census conducted in Ireland, there were 139 growers of organic crops, of which 77 were producers of organic vegetables (Department of Agriculture Fisheries and Food, 2003). The largest producing counties of organic vegetables in Ireland are Cork (16%), Galway (12%), Wicklow (9%) and Clare (9%) (Department of Agriculture Fisheries and Food, 2003).

1.5.2 CONVENTIONAL VEGETABLE PRODUCTION

According to Bord Bia (2009b) the Irish retail market for fresh produce was valued at €1.2 billion in 2007. The retail market for fresh produce comprise sales of fruits (45.5%), salad vegetables (14.2%), vegetables (23.6%) and potatoes (16.7%).

The actual farmgate value of the horticultural food sector in Ireland was €328 million in 2007 (Fig. 1.20), with approximately 1,400 horticultural food growers producing a range of vegetables including potatoes, field vegetables, mushrooms and protected crops (Bord Bia, 2009c). Horticultural crops are produced throughout Ireland, however field vegetables are primarily cultivated in Leinster and Munster, potatoes are grown mainly in Leinster, Munster and Ulster, while the protected crops (tomatoes, lettuce, cucumbers, etc) are produced largely in Leinster (Bord Bia, 2009d).

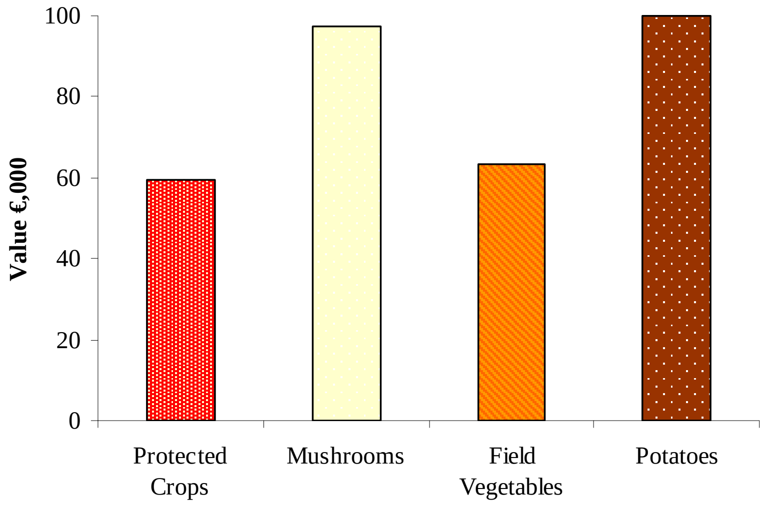


Fig. 1.20: The value of key horticultural crops produced in Ireland, 2007 (adapted from Bord Bia, 2009d).

1.5.3 CARROTS

The carrot (*Daucus carota*) belongs to *Apiaceae* family (Christensen *et al*., 2007). It is a herbaceous biennial plant. It has been reported that the annual global carrot production was estimated at 23,607,214 metric tonnes in 2004, with China producing more than 28% of the world's carrots, followed by the United States with 10% and Russia with 7.2% (FAOSTAT, 2004). In Ireland, the carrot is the most important root vegetable, in terms of production area and market value (Bord Bia, 2005). Approximately 718 hectares of conventional carrots were grown with an estimated farmgate value of €12.5 million in 2005 (Bord Bia, 2005). No detailed data is available for organic carrot production. However, it was reported that carrots were the most popular vegetable purchased by organic consumers (71%) in 2007 (Bord Bia, 2008b).

Typical conventional carrot varieties grown in Ireland include Nairobi, Nantes, Nandor, Primo, Narbonne, Bolero, Narvarre and Anglia (Bord Glas, 1995). While, common organic varieties include Chantenay red, Laguna, Merida, Nairobi and Nantes (The Organic Centre, 2009). Carrots are generally available on the Irish market from mid/late May to early/mid April in the following year (Bord Bia, 2009e).

1.5.4 POTATOES

The potato (*Solanum tuberosum* L.) is a member of the *Solananceae* family (Gould, 1999). The potato is the fourth most widely grown crop in the world after wheat, maize and rice (Vreugdenhil *et al.*, 2007). It is especially important in the Irish diet, where it is still the primary carbohydrate source at main meals, whereas bread, pasta and rice tend to be the main source of carbohydrates in the rest of Europe (Teagasc, 2007b). Global potato production was estimated at 321.69 million tonnes in 2007, with Asia and Europe producing more than 80% of the world's potatoes (FAOSTAT, 2008). China is the largest potato producer in the world, with 72 million tonnes of potato produced in 2007 (FAOSTAT, 2008). Within Europe, Germany and Poland are the largest producers of potatoes, each with approximately 11 million tonnes, while Ireland, Great Britain and Portugal have per capita consumption of about 100kg per annum (Storey, 2007). In 2007, 11,700 hectares of land was used for potato production in Ireland, with an average yield of 34,000 tonnes per hectare (Central Statistics Office, 2009). No detailed data is available for organic potato production. However, it was reported that potatoes were the second most popular vegetable purchased by organic consumers (58%) in 2007 (Bord Bia, 2008b). Typical conventional potato varieties grown in Ireland include Rooster, Kerr's Pink, Record, Maris Piper, Cara, Golden Wonder, Orla and Setanta. Organic varieties that grow well in Ireland are Orla, Setanta, Druid, Cara and Kikko (Irish Potato Marketing, 2009). Potatoes are usually harvested on an annual basis in Ireland between the months of July and March (Bord Bia, 2009f).

1.5.5 TOMATOES

The tomato (*Lycopersicon esculentum*) is also a member of the *Solanaceae* family (Davies and Hobson, 1981). Botanically, the tomato is considered a berry fruit, but it is cultivated and used as a vegetable (Petró-Turza, 1987). The tomato is the second most important vegetable crop after potatoes, with world production of 100 million tonnes in 2003 (FAOSTAT, 2004). China is the largest producer of tomatoes in the world, producing approximately 30,142,000 metric tonnes in 2003 (FAOSTAT, 2004). The tomato is the most important protected vegetable crop in Ireland (Bord Bia, 2004), with tomato production valued at €7.6 million in 2004. No detailed data is available for organic tomato production. However, it was reported that tomatoes were the third most popular vegetable purchased by organic consumers (46%) in 2007 (Bord Bia, 2008b). Tomatoes are generally harvested between the months of April and October in Ireland (Bord Bia, 2009g).

Typical conventional tomato varieties grown in Ireland include Alicante, Roma, Gardeners Delight, Flavorita and Amoroso (Hessayon, 2005). While organic tomato varieties include Agro, Amoroso, Cindel, Claree and Piccolo (The Organic Centre, 2009).

1.6 ENVIRONMENTAL FACTORS AFFECTING THE GROWTH AND PRODUCTION OF ORGANIC AND CONVENTIONAL VEGETABLES

Fresh vegetables are living organisms, so it is not surprising that several agronomic factors affect carrot, potato and tomato sensory quality. Genetic variation and environmental conditions can greatly influence the sensory quality of carrots (Baardseth *et al.,* 1996; Hogstad *et al.*, 1997). With reference to potatoes, Burton (1989) reported that preharvest practices and postharvest management can affect the chemical composition of the potato tubers. Plant exposure to water stress may reduce potato tuber yield (Jefferies, 1989), while, tomatoes which are exposed to the sunlight maybe of a different quality to those which grow in the shade (Grierson and Kader, 1986).

1.6.1 GROWING MEDIUM

1.6.1.1 SOIL

Vegetables can be grown on a range of soil types. Carrots prefer light, open and deep soils that are well drained and retain moisture well (Nonnecke, 1989). Heavy soils such as clays can be fertile and therefore productive for potatoes (Teagasc, 2008). While, tomatoes require a siliceous-clay loose, deep and well-drained soils that are rich in organic matter (Herrera *et al.*, 1999). The soil pH influences the rate of nutrient release through weathering, the solubility of all the materials in the soil, and the quantity of nutrient ions stored in the cation exchange complexes. The optimum pH is usually between 6.0 and 7.5, because all the nutrients are reasonably available to plants in this range of pH values.

Carrots and potatoes grow best in soils with a pH between 5.5 and 6.8, whereas the optimum pH for tomatoes is between 6 and 7 (Herrera *et al.*, 1999).

1.6.1.2 ROCKWOOL

Although, mineral soil is the universal culture medium for plant growth, it is being gradually replaced by substrates with a higher percentage of organic matter (Vainburg *et al.*, 2008). Hydroponic cultivation consists of replacing the soil with a natural or artificial substrate that maybe solid or liquid. Rockwool is an inorganic material obtained by mixing diabase (60%), limestone (20%) and coal (20%) in solution at 1,600^{o}C (Smith, 1987). It is an artificial substrate, but is not totally inert as it supplies small quantities of iron, magnesium, manganese and especially calcium.

1.6.2 SALINITY

According to Datta and de Jong (2002) an increase in the amount of salts dissolved in water makes it harder for the plant to take up nutrients (due to osmosis, water tends to leave roots instead of entering them bearing nutrients). In fact, excessive concentrations of some salts are phytotoxic to plants. For instance, carrots are particularly sensitive to salinity (Kumar *et al.*, 2004). However, salt stress has been found to increase sugar content in tomatoes (Adams and Ho, 1992).

1.6.3 LIGHT

Vegetables which are constantly exposed to the sun maybe of different quality to those which are shaded from the sun. Grierson and Kader (1986) reported that light intensity during the growing period had a significant effect on the sugar and acid content of tomatoes. They reported that although ripening itself can occur in the dark and is not much influenced by light, sugar content is closely correlated with solar radiation during fruit growth and high irradiance leads to high concentrations of sugar in the fruit.

1.6.4 TEMPERATURE

The temperature at which a vegetable crop is grown at can influence its quality and post harvest life. Each crop requires a special set of temperature conditions, which determine its growth and future production. The temperature at which a vegetable crop is grown at is perhaps the most important factor that affects growth and development of the vegetable, as it affects almost all its biochemical processes, such as photosynthesis, respiration and transpiration (Herrera *et al.*, 1999). The carrot is capable of growing anywhere provided the growing season remains relatively cool, however, the optimum temperature range is between 16-18^{o}C (Eskin, 1989). When the air temperatures rise above 21^{o}C, root growth is reduced. For potatoes, it is recommended that temperatures during the growing season never fall below 5^{o}C or exceed 21^{o}C (Burton, 1989). Lower temperatures lead to risk of damage due to frost, and at higher temperatures the translocation of dry matter to the tubers is much reduced (Vos and Haverkort, 2007). For tomatoes, low temperatures tend to reduce lycopene synthesis (Koskitalo and Ormond, 1972). While, temperatures above 30^{o}C can inhibit lycopene production altogether (Tomes, 1963). Exposure of mature-green tomatoes to temperatures above 30^{o}C can result in irregular ripening of tomatoes (yellow and greenish-yellow areas on red ripe tomatoes). Ethylene production and the synthesis of the softening enzyme polygalacturonase are also inhibited at high temperatures (Grierson and Kader, 1986).

1.6.5 MOISTURE

Moisture influences a wide range of physiological processes in plants (Galindo *et al.*, 2004). Water is essential for sugar production and to maintain healthy cells. It is the transport medium for nutrients within the plant and for substances the plant produces, as well as being the primary reagent in many basic physiological processes. Additionally, the turgor of the entire plant, also depends on water. In leafy green vegetables too much rain or irrigation results in the leaves becoming hard and brittle, which in turn makes them more susceptible to damage and decay during harvesting and storage (Thompson, 1996). For carrots, differences in soil moisture can affect root yield, shape, sugar and dry matter content (Eskin, 1989).While, it has been reported that water availability can significantly reduce the harvest index of a potato crop (Vos and Haverkort, 2007). For tomatoes, it was reported that reduced soil moisture increases sugar content (Grierson and Kader, 1986).

1.6.6 PESTS AND FUNGAL DISEASES

Carrot crops are regularly susceptible to an attack from carrot fly, wireworms, cutworms, aphids and nematodes and typical fungal diseases which carrots are exposed to include root black rot, *Alternaria*, *Cercospora*, mildew and powdery mildew (Herrera *et al.*, 1999). Potato crops are particularly susceptible to attack from nematodes, wireworms and slugs and common fungal diseases of potatoes include potato blight, stalk break, stem canker, skin spot, verticillium wilt and wart disease (Burton, 1989). According to Hessayon (2005), tomatoes are vulnerable to attacks from tomato grub, cutworms, wireworms, whitefly, tomato mites, red spider mites and nematodes, as well as some fungal diseases (tomato mildew, *Alternaria*, *Cladosporium*, tomato anthracnose, tomato powdery mildew and *Botrytis*).

The control of pests and diseases are usually achieved by spraying crops with chemical pesticides, fungicides and insecticides. However, synthetic chemical inputs are not permitted in organic farming. According to Teagasc (2008), crop rotations are essential for effective pest and disease management in organic farming. Additional controls used by growers include physical barriers such as insect mesh crop and biological controls i.e. parasitic wasps *Encarsia Formosa* (Organic Matters, 2009).

1.6.7 FERTILISERS

Applying fertilisers (farm yard manures, dung, mixes of synthesised chemicals, and inputs of nutrient rich minerals) to plants is one way of artificially altering the quantity of ions in the soil solution, in order to increase crop yields.

The amounts of fertiliser required for maximum yields will depend on environmental factors such as soil type, soil mineral concentrations and weather conditions, agronomic factors such as timing, location and chemical form of the fertiliser applied and genetic factors such as longevity, growth rate and tissue mineral requirements of the vegetable crop (White *et al.*, 2005).

1.6.7.1 SYNTHETIC FERTILISERS

Synthetic fertilisers are composed of simple chemicals and minerals which have been manufactured through a chemical process. The usual way of describing a synthetic chemical fertiliser is by using a series of three numbers that represent the percentages of N-P-K (nitrogen, phosphorus and potassium). Fertiliser mixes are fertilisers that contain two or three elements and have been obtained by mechanically mixing simple compounds together, sometimes with a little water so they form granules, and maybe binary (P-K combinations) or ternary (N-P-K combinations).

1.6.7.2 ORGANIC FERTILISERS

Organic fertilisers consist of organic matter or dung, mainly from stock piling farms. In horticultural crops, the dung used should be well rotted, and is usually applied at a rate of 30 to 50 t ha^{-1}, depending on the species being cultivated, the expected production, the application system and the rotation being followed (Herrera *et al.*, 1999).

The amount of nutrients contained in 1 tonne of organic fertiliser is listed in Table 1.2.

Table 1.2: Amount of nutrients contained in 1 tonne of organic fertiliser (adapted from Statutory Instrument, 2009).

Live stock type	Total Nitrogen (kg)	Total Phosphorus (kg)
Poultry manure:		
Broilers	11	6
Layers 55% dry matter	23	5.5
Turkeys	28	13.8
Dungstead manure (cattle)	3.5	0.9
Farmyard Manure	4.5	1.2
Spent Mushroom Compost	8	2.5

Regardless of the type of nitrogen fertiliser (inorganic, organic or manures), plants use nitrogen only in the form of nitrate (NO_3-) and ammonium (NH_4+). Nitrogen containing compounds are broken down into free ammonium, which is converted into ammonia and ammonia salts. Microorganisms break down ammonia into nitrite (NO_2-) and then to nitrate (NO_3-). Nitrate (NO_3-) and ammonium (NH_4+) are dissolved in the soil water and are taken up by the plant. Nutrients from organic fertilisers are released more slowly and steadily to the plant (Montagu and Goh, 1990), whereas synthetic fertilisers offer more readily available sources of nitrogen, to accelerate plant growth (Faller and Fialho, 2009).

1.6.8 MINERAL COMPOSITION OF FERTILISERS

The three basic elements required for plant nutrition are nitrogen, phosphorus and potassium. In addition to this, sulphur, calcium and magnesium are secondary elements required in plant nutrition. Plants need less of them than the macronutrients but more than the microelements. The essential microelements are iron, manganese, copper, zinc, boron, molybdenum and chloride. These are required in tiny quantities, but a deficiency may cause serious disorders of the plants metabolism (Herrera *et al.*, 1999).

1.6.8.1 NITROGEN

Nitrogen stimulates plant growth, however application of excessive amounts have been reported to result in significant reductions in the yields obtained (O’Beirne and Cassidy, 1990; Maggio *et al*., 2008). In addition to this, Kader (2002) reported that excessive nitrogen fertilisation can result in a reduction in the amount of carotene produced in carrots and consequently, a loss in colour, for carrots.

For potatoes, excessive nitrogen supply, may result in very lush leaf growth, but may also have a detrimental effect on the dry matter content in the tuber (Burke, 2003).

While, Wright and Harris (1985) found that tomatoes which were fertilised with large amounts of nitrogen received lower sensory scores than those which received little or no nitrogen.

1.6.8.2 PHOSPHORUS

Phosphorus is extremely important for the stimulation of root growth for carrots, and advanced flowering and fruit formation for tomatoes (Winch, 2007).

In terms of potatoes, the effects of phosphorus fertilisation on tuber yield are thought to be a direct consequence of increased leaf index, ground cover and radiation absorption (Harris, 1992; White *et al*., 2005).

1.6.8.3 POTASSIUM

The function of fertilising crops with potassium is to improve plant quality, increase the plants resistance to water shortages, by lowering transpiration and to assist in the formation of chlorophyll (Winch, 2007).

For potatoes, Harrison *et al.* (1982) reported that increased rates of potassium fertilisation reduced the specific gravity of potato tubers. While Grierson and Kader (1986) noted that potassium content has a significant effect on the sugar and acid content of tomatoes. The higher the potassium content the greater the flavour of the tomatoes.

1.6.8.4 SECONDARY MACRONUTRIENTS: CALCIUM, SULPHUR AND MAGNESIUM

According to Herrera *et al*. (1999) calcium, sulphur and magnesium have an important role to play regarding plant growth. Calcium is important for plant growth, fruit formation and ripening. While, sulphur along with nitrogen and phosphorus is vital for protein synthesis. In addition to this, magnesium is required for production of chlorophyll and it also helps phosphorus uptake.

1.7 THE SENSORY QUALITY OF ORGANIC AND CONVENTIONAL VEGETABLES

A review of claims that organically farmed vegetables taste better and are more nutritious found these claims to be largely unsubstantiated (Woese *et al.,* 1997). Although on superficial examination, their review was thought to represent a substantial body of knowledge, the authors drew serious shortcomings of many of the studies published with particular reference to limited information provided about the growing systems as a whole, and a lack of rigorously controlled conditions. It concluded that greater scientific rigour was needed if quality differences between organic and conventional vegetables were to be found. Several authors reported similar findings (Heaton, 2001; Bourn and Prescott, 2002; Lester, 2006; Theuer, 2006). A common theme among many of these studies was variability, which stems from an inability to control environmental factors which impact on plant development. Examples of this are cultivar selection (Bordeleau *et al*., 2002), physiological age (Basker, 1992; Wszelaki *et al*., 2005; Zhao *et al*., 2007) and soil type (Porretta, 1994; Haglund *et al*., 1999). Other authors did not disclose any experimental details for their publications (Dlouhy, 1977; Rader *et al*., 1985) Valid quality comparisons between organic and conventional vegetables require that the crops be cultivated under similar agronomic and environmental conditions (Magkos *et al*., 2003). Without this information, the task of interpreting data becomes more difficult and there remains a high level of uncertainty regarding conclusions (Lester, 2006). In addition to this, various studies have shown that providing positive information about organic vegetables to sensory panels prior to conducting sensory evaluations influenced hedonic sensory judgments favourably (Hansen, 1981, Johansson *et al*., 1999).

Research studies to date have focused on comparing the physicochemical components (Bordeleau, 2002) or chemical composition and sensory analysis (Maga *et al*., 1976; Hajŝlová *et al*., 2005; Wszelaki *et al*., 2005; Barrett *et al*., 2007), or just the sensory properties (Basker, 1992; Haglund *et al.*, 1999; Zhao *et al*., 2007) of organic and conventional vegetables. The characteristic flavour of vegetables is largely attributed to their volatile composition (Petró-Turza, 1987; Maga, 1994; Krumbien *et al.*, 2004; Kalua *et al.*, 2007; Kreutzmann *et al.*, 2008). In spite of this, all available studies to date have neglected to take into account this highly important parameter of sensory quality. Research on the flavour quality of organic and conventional should include analysis of both volatile and non volatile constituents.

A thorough review of the literature to date has revealed that there is no definitive scientific testing system available to compare the sensory properties of organic and conventional vegetables. In addition, no Irish studies have been undertaken on the sensory properties of organic and conventional vegetables, whether raw or cooked.

1.8 RESEARCH AIMS AND OBJECTIVES

There is so much conflicting scientific data on the sensory merits of organic vegetables that it is necessary to establish a novel, reliable and validated testing protocol for comparing organic and conventional vegetables. This novel testing protocol will examine the physicochemical composition, volatile emissions and the sensory properties of organic and conventional vegetables under controlled conditions. The information from future studies conducted by other researchers using this innovative testing protocol could be used to provide factual and dependable information to growers, educators and policymakers alike. Transparency will be conferred and reliable information offered to consumers so that they can make an informed choice when purchasing organic vegetables.

This can be done through the following objectives

- Examine the effect of the growing system on the physicochemical properties of organic and conventional carrots, potatoes and tomatoes, before and after cooking.
- Determine the volatile flavour profiles of Irish grown organic and conventional carrot, potato and tomato varieties.
- Investigate the effect of the growing system on the sensory properties of organic and conventional carrots, potatoes and tomatoes, before and after cooking.
- Establish if selected Irish organic vegetables (raw or cooked) have a better flavour than selected Irish conventional vegetables (raw or cooked).
- Test the hypothesis that consumer preference for organically farmed vegetables is significantly higher than that of conventionally produced vegetables.

CHAPTER 2

2.1 PLANT MATERIALS

2.1.1 CARROT

Organic and conventional carrots (*cv*. Nairobi) were selected for this study. It was not feasible to collect the carrots directly from the farms, therefore contact was made with the growers to arrange for collection in Dublin. Upon harvesting, the carrots were delivered to and collected within 24 hours from a supermarket in Dublin (Superquinn, Blackrock) in November and December 2008. The organic carrots were cultivated in County Offaly, while the conventional carrots were grown in County Wexford. The organic and conventional carrots were grown in brown earth and sandy loam soils respectively. In this study, the organic carrot crop was fertilised with a farmyard manure at a rate of 20,000 kg ha^{-1} and compost teas. While, the conventional crop was fertilised with a synthetic binary P-K fertiliser at a rate of (5-15) 1000 kg ha^{-1}. The conventional crop was also treated with 20 kg N ha^{-1}. Insect crop covers were used to protect the organic and conventional crops from pests. In addition to this, the conventional carrot crop was treated with two fungicides, Amistar and Folicur, as well as the synthetic insecticide, Karate. The organic growing system was approved by The Organic Trust of Ireland.

2.1.2 POTATO

Organically farmed and conventionally produced potatoes (*cv*. Orla) were collected from two sites in Navan, County Meath in Ireland. The organic and conventional potatoes were grown in a clay loam soil. In this study, the organic crop was fertilised with a composted farmyard manure at a rate of 25,000 kg ha^{-1} annually. While, the conventional crop was fertilised with a synthetic N-P-K fertiliser at a rate of (10-10-20) 1235 kg ha^{-1} annually. In addition to this, Burgundy (copper sulphate and washing soda) was applied to the organic potato crop at a rate of 15 kg ha^{-1} to protect the potato crop against potato blight. The conventional potato crop was sprayed with a commercial liquid copper fungicide blight spray. Both the farmyard manure and fertilisers were applied to the soil before sowing the organic and conventional potatoes. The organic growing system was approved by The Organic Trust of Ireland. The organic and conventional potatoes were planted during the month of June 2008 and were harvested during the months of October and November 2008.

2.1.3 TOMATO

Both the organically farmed and conventionally produced cherry vine tomatoes (*cv*. Amoroso) were collected at the red ripe stage (Bord Glas, 1999) from two sites in North County Dublin, Ireland. The organic and conventional cherry vine tomatoes were grown in heated glasshouses. The organic cherry vine tomatoes were grown in brown earth soils treated with grass cuttings and compost. Woodash was incorporated into the soil at planting. The organic cherry vine tomato crop was fed with a commercial organic liquid seaweed fertiliser. Each organic cherry vine tomato plant was supplied with ~2L of water a day during the growing season. The average temperature recorded in the greenhouse was 23^{o}C. Greenfly and whitefly were controlled using, parasitic wasps (*Encarsia formosa*) and bumblebees were used to pollinate the flowers on the plants. Greenhouse maintenance was conducted on a weekly basis. The organic growing system was approved by The Organic Trust of Ireland. The conventional cherry vine tomato plants were planted in rockwool slabs (Grodan, Roermond, Holland). Four cherry vine tomato plants were transplanted in each rockwool slab. The nutrient solution was applied via a complex computerised drip irrigation system, which was activated at approximately 8.00 hrs each morning until 18.00 hrs each evening. The nutrient solution contained $Ca(NO_3)_2$, KNO_3, $(NH_4)_2SO_4$, K_2SO_4, $(NH_2)_2CO$, $MgSO_4$, $(NH_4)(NO_3)$, Fe, Mg, Zn, Cu, Mo, B and Mn. The average EC value of the nutrient solution was 3 dSm^{-1} and the average pH of the nutrient solution was 5.5. The nutrient solution was supplied on average seven times on a daily basis over the growing season. The supply was adjusted according to plant size and environmental conditions. The greenhouse did not have any cooling system in operation, but the temperature was cooled by ventilation. Two heating systems were in operation in the greenhouse, one located in the floor, the other located beside the plants, so that the heat would be transferred directly onto the vines. Average, maximum and minimum temperatures in the greenhouse were 21^oC, 25^oC and 18^oC, respectively. The average relative humidity was 80%, while the average CO_2 level was 800 ppm, but this was dependant of plant size and environmental conditions. Pests were controlled using parasitic wasps (*Encarsia formosa*) and predatory insects (*Macrolophus caliginosus*). In addition to this, greenhouse maintenance, which included leaf pruning, removal of side shoots and the trimming of trusses, was conducted on a weekly basis. The conventional tomatoes were also pollinated by bumblebees. Both the organic and conventional cherry vine tomatoes were harvested in July, August and September 2007.

2.2 SAMPLE PREPARATION

2.2.1 SAMPLE PREPARATION FOR RAW VEGETABLES

On arrival to the food processing laboratory, the vegetables were washed in cold water, gently dried with paper towels and their size measurements (weights, lengths, diameters) were taken (Day 0). All samples (organic and conventional) except the potatoes were stored in a refrigerator (Hotpoint, Iced Diamond, Peterborough, UK) at 4^{o}C for 18 hrs prior to testing. The potatoes were stored in a dry store at 20^{o}C for 18 hrs prior to testing. All physicochemical tests were carried out on Day 1, and volatile analysis and sensory analysis by the trained sensory panel was carried out on Day 2. Consumer sensory evaluations were carried out on a separate vegetable batch.

2.2.1.1 CARROTS

The carrots were manually peeled, topped and tailed using a sharp knife, rewashed and allowed drip-dry in a colander for 15 min. The carrots were cut into 2 cm long, 1 cm wide, and 1 cm thick sticks. The carrots were divided into 100 g lots and were placed in P+ bags 200x250 mm^2 (Amcor Flexibles, Ledbury, UK). The P+ bags were constructed using a 35 µm thick orientated polypropylene (OPP) film. The bags were heat sealed using an impulse heat sealer (SMS, Packer Products, Basildon, UK).

2.2.1.2 POTATOES

Whole organic and conventional potato samples were used for instrumental and sensory analysis.

Samples were prepared for analytical determinations and sensory evaluation as outlined in the physicochemical study and sensory study (See 2.3 and 2.4).

2.2.1.3 TOMATOES

For instrumental analysis, the tomatoes were cut in half longitudinally (stem scar to blossoms end). The tomato halves (200 g) were laid on plastic trays, placed into the P+ bags (Amcor Flexibles, Ledbury, UK) and sealed. For sensory analysis purposes, whole organic and conventional tomatoes were presented to the sensory panel for evaluation.

2.2.2 SAMPLE PREPARATION FOR COOKED VEGETABLES

Samples were prepared as previously described for the raw vegetables.

2.2.2.1 CARROTS

Carrot batons were steamed in 200 g batches using a domestic steamer (FS360 Kenwood, Food Steamer, Hampshire, UK) for 7.5 mins (Turkmen *et al*., 2005). After steaming, the carrots were removed from the steamer and were drained. The carrots were then cooled to 4^oC in a blast chiller (Foster BQC 45, Berkshire, UK) for instrumental analysis. Once cooled, the carrot samples were packed into P+ bags 200x250 mm^2 (Amcor Flexibles, Ledbury, UK). Samples required for instrumental analysis were tested immediately. Samples required for volatile analysis were stored in a refrigerator at 4^oC for 18 hrs. For sensory analysis, the carrots were presented directly to the sensory panel for sensory evaluation once cooked.

2.2.2.2 POTATOES

The method for preparing the baked potatoes was previously described by Oruna-Concha *et al.* (2002). The potatoes were pierced three times with a fork, to a depth ~1 cm, and were covered in aluminium foil, before baking. They were baked at 190^{o}C for 1 hour in a fan assisted oven (Rational Combi-Oven, Landsberg, Germany). After baking the potatoes were cooled to 4^{o}C in a blast chiller (Foster BQC 45, Berkshire, UK). The potato samples were packed into P+ bags 200x250 mm^{2} (Amcor Flexibles, Ledbury, UK). Sample analysis was performed as described in section 2.2.2.1.

2.2.2.3 TOMATOES

Whole tomatoes (flesh and peel) were homogenized using a hand blender (Morphy Richards Limited, Mexborough, UK) for 2 min. Each sample of fresh tomato homogenate (300 g) was transferred to a stainless steel pot and was heated to 80^{o}C for 7 min, on an electric hob (DeDietrich Kitchen Appliances, Hampshire, UK). The heated tomato macerate was cooled to 4^{o}C in a blast chiller (Foster BQC 45, Berkshire, UK) Once cool, the heated tomato macerate was packed into plastic bags (Amcor) and sealed. Sample analysis was performed as described in section 2.2.2.1.

2.3 PHYSICOCHEMICAL STUDY

For raw vegetable trials, three separate batches of organic and conventional carrots, and potatoes were tested. Ten replicates from each batch of carrot and potato were tested each time (organic: n=30; conventional: n=30). For the raw tomatoes, nine separate batches of organic and conventional tomatoes were tested. Fourteen replicates from each batch of tomato were tested each time (organic: n=126; conventional: n=126).

For the cooked vegetable trials, three separate batches of organic and conventional steamed carrots, baked potatoes, and heated tomato were tested. Ten replicates from each batch of carrot, potato and tomato were tested each time (organic: n=30; conventional: n=30).

2.3.1 SIZE MEASUREMENTS

The fresh raw carrots were weighed (TE4101, Sartorius, Goettingen, Germany) and their diameters and lengths were measured with a vernier callipers (5921, Measy 2000, Switzerland). The cylindrical form of the root (C-value) was determined according to Baardseth *et al*. (1996) using equation 2.1.

Equation 2.1: Calculating the cylindrical form of the carrot root

$$C = \frac{W}{\pi r^2 L}$$

where:

W= weight in g

L= length in cm

r = radius in cm, taken to half the diameter.

The value of C must lie between 0.33 and 1.0, the limiting values being obtained for the perfect cone and cylinder, respectively.

Similarly, the raw potato samples were weighed (TE4101, Sartorius, Goettingen, Germany) and their diameters and lengths were measured with a vernier callipers (5921, Measy 2000, Switzerland) and recorded. For the fresh tomato samples, the longitudinal diameter (stem scar to blossom end), cross-sectional diameter (transverse diameter) and stem scar were measured on whole tomatoes using a vernier callipers (5921, Measy 2000, Switzerland) and the results were expressed as mm (Garcia and Barrett, 2005). The tomato samples were also weighed using an analytical balance (TE4101, Sartorius, Goettingen, Germany).

2.3.2 COLOUR ANALYSIS

Colour measurements were made using a Colorflex Spectrophotometer (Hunter Associates Laboratory Inc., Virginia, USA) which was calibrated with a white standard tile and a light trap. The illuminant chosen was D65 and the observer used was 10^{o}. The CIELAB system as specified by the International Commission on Illumination, was used to determine the colour of the vegetable samples. The L*(L*=0 indicates black, while L*=100 signifies diffuse white), a*(a positive a* value indicates red colour, while a negative a* value suggests a green colour), and b*(a positive b* signifies a yellow colour, whereas a negative b* value signifies a blue colour) values were documented.

From these readings chroma and hue angle (Busch *et al.*, 2008) were determined using the following formulae:

Equation 2.2: Calculating the chroma values

$C^* = (a^{*2}+b^{*2})^{½}$

Equation 2.3: Calculating the hue angle

$H^* = \tan^{-1}(b^*/a^*)$.

The colour of the raw and cooked carrot batons was determined using a method as outlined by Redmond *et al*. (2004). Four random areas were measured on the internal and external surface per potato (raw and cooked) as previously described by Pardo *et al*. (2000). For the raw tomatoes, colour measurements were made at three different places on the tomato surface (one at the blossom's end and two in the equatorial zone) as described by Brandt *et al*. (2006). In addition to the chroma and hue values, the a*/b* value (Gormley and Egan, 1978) was also determined for tomatoes.

The approximate a*/b* colour values for tomatoes at different stages of ripeness are presented in Table 2.1.

Table 2.1: Approximate a*/b* values for tomato fruit at different stages of ripeness (adapted from Gormley and Egan, 1978).

Colour Description	a*/b* Colour Value
Green/Green Yellow	0.01-0.20
Half Red (50% Yellow and Red)	0.50
Red Ripe	1.40
Dark Red (Overripe)	$\geq$1.90

For the cooked tomato macerate, samples were placed into a petri dish and the L*, a*, b*, chroma and hue colour values were recorded as described by Sánchez-Moreno *et al*. (2006).

2.3.3 TEXTURE MEASUREMENTS

The texture of the vegetables was measured using an Instron Universal Testing Machine (4464, Instron Corp., High Wycombe, UK). The firmness of the raw and cooked carrots was measured by perforating each carrot stick with a 7 mm-diameter puncture probe, at a crosshead speed set at 200 mm/min as described by Rocha *et al*. (2007). The load cell of 500 N was used. The maximum puncture force (N) was recorded. The data was analysed using Bluehill software (Version 2.0.0, Illinois, USA). For the raw and cooked potatoes, two thin longitudinal sections (bud end-stem end), approximately 20 mm thick, were taken using a handheld slicer (Gourmet V-Slicer, Nottingham, UK). The potato samples were punctured using a 7 mm-diameter probe at a crosshead speed set at 200 mm/min. A load cell of 500 N was used and 4 puncture tests were performed for each replicate. The maximum puncture force (N) was recorded. The data was analysed using Bluehill software (Version 2.0.0, Illinois, USA). This method was performed as previously described by Abu-Ghannam and Crowley (2006). Tomato fruit firmness was determined by puncturing a tomato sample, using a 7 mm-diameter probe at a crosshead speed set at 200 mm/min. A load cell of 500 N was used. The tomatoes were sliced in half from the stem scar through to the blossom's end. Measurements were made at two different places on the fruit surface both in the equatorial region. The maximum puncture force (N) was recorded. The data was analysed using Instron Series IX software (Version 8.25, Illinois, USA).

The viscosity of the processed tomato macerate was determined using a Brookfield Dial Reading Viscometer (Brookfield Viscometers Limited, Essex, UK) using the method as described by Weaver (2003). The viscometer was calibrated before use. Three hundred millilitres of cooked organic tomato macerate and of cooked conventional tomato macerate was placed into each of three 500 ml beakers. The viscosities of the respective tomato samples were determined at 20^{o}C. The speed control was set at 50 rpm. Measurements were taken 2 minutes after the spindle (No. 1) was immersed in the tomato macerate.

2.3.4 DRY MATTER ANALYSIS

The dry matter content of the raw and cooked vegetables was determined using a method as outlined by AOAC (1990). Two gram samples of each of the raw and cooked vegetables were weighed and then dried in an oven (Universal Oven, Memmert, Schwabach, Germany) at 105°C for 24 h. Following this, the samples were removed from the oven, cooled in a desiccator and weighed.

Percentage moisture (Equation 2.4) and percentage solids (Equation 2.5) were calculated using the following formulae as described by Park (1996).

Equation 2.4: Calculating % moisture content of raw and cooked vegetable samples.

$$\%Moisture = \frac{weightloss(g)}{wetweight(g)} \mathrm{x}100$$

Equation 2.5: Calculating % solids of raw and cooked vegetable samples.

$$\%Solids = 100 - \%Moisture$$

2.3.5 ACIDITY MEASUREMENT

The acidity value of each of the raw vegetable samples was determined instrumentally using a method developed by Wrolstad *et al.* (2005). Before measuring the acidity of the vegetables, the pH meter (420A, Orion pH meter, USA) was calibrated using standard buffer solutions pH 4, 7 and 10. Then, the electrode was rinsed with doubly distilled water and dried off. The pH was measured in the juice obtained after washing and crushing the samples (Breville Anthony Worrall Thompson Juicer, Lancashire, U.K). The electrode was then placed into the vegetable sample and was stirred slowly. The pH meter was allowed to stabilize and the acidity value of the sample was recorded. For the cooked vegetable samples, the pH was measured according to a method by Low *et al*. (2006). Ten gram samples of cooked vegetable sample was mixed with 20 mL of sonicated distilled water. The pH was measured at 20°C using a pH meter (Orion pH meter Model 420A, USA).

2.3.6 SOLUBLE SOLIDS ANALYSIS

The juice of the freshly macerated raw vegetable samples was used to determine soluble solids content of the vegetables. The juice of a vegetable sample was placed onto a refractometer (VWR Handheld Refractometer, 0-50% Brix ATC, Germany) and the readings were recorded (Pardo *et al.*, 2000). The results were expressed in °Brix. Data was expressed as g soluble solids per 100 g fresh weight. For the cooked vegetable samples, ten gram samples of cooked vegetable sample was homogenised with 20 mL of sonicated distilled water. The °Brix of the cooked vegetables samples was measured at 20°C using a refractometer (VWR Handheld Refractometer, 0-50% Brix ATC, Germany).

2.3.7 SUGAR ANALYSIS

The sugar content of each of the raw and cooked vegetables were determined using an enzymatic kit (K-SUFRG, Megazyme, Wicklow, Ireland). The method was as follows:

2.3.7.1 SAMPLE PREPARATION

1 gram of vegetable macerate was weighed and transferred into a 100 mL volumetric flask, which contained 60 mL of distilled water. 5 mL of Carrez I solution (3.60 g potassium hexacyanoferrate (II) and 100 mL distilled water), 5mL of Carrez II solution (7.20 g zinc sulphate and 100 mL of distilled water) and 10 mL of NaOH solution (4 g Sodium

hydroxide and 100 mL distilled water) was added. The solution was mixed after each addition. The flask was filled to the mark with distilled water and was shaken vigorously for 5 min. The solution was then filtered through Whatman No.1 filter paper.

2.3.7.2 DETERMINATION OF FREE D-GLUCOSE AND FREE D-FRUCTOSE

The concentrations of free D-glucose and free D-fructose present in the vegetable samples were quantified using an enzymatic kit (K-SUFRG, Megazyme, Wicklow, Ireland). Firstly, 0.10 mL of the prepared sample solution was placed into a cuvette and to this 2.10 mL of distilled water, 0.10 mL of imidazole buffer and 0.10 mL of $NADP^+$/ATP was added. In another cuvette, the blank sample, 2.20 mL of distilled water, 0.10 mL of imidazole buffer and 0.10 mL of $NADP^+$/ATP was added. Both cuvettes were mixed by gentle inversion after sealing them with Parafilm®, and were then placed into the UV/VIS spectrophotometer (Milton Roy Spectronic 1201, Pennsylvania, USA) which had the wavelength set at 340 nm. The absorbances of the solutions (A_1) were read.

Following this, 0.02 mL of hexokinase and glucose-6-phosphate dehydrogenase suspension was added to both cuvettes. The samples were gently mixed and the absorbances were documented for each of the solutions at the end of the reaction (A_2), which took approximately 5 min. To this, 0.02 mL of phosphoglucose isomerase suspension was added to both samples. Both samples were gently mixed and returned to the spectrophotometer for further analysis. The absorbances were recorded after approximately 10 min (A_3).

Differences in the absorbance readings, (A_2-A_1) and (A_3-A_2) for the blank and sample were determined and from this, values of $^{\Delta A}$D-glucose and $^{\Delta A}$D-fructose were calculated according to the following equations:

Equation 2.6: Calculating ΔAD-glucose of raw and cooked vegetable samples.

$^{\Delta A}$D-glucose = (A_2-A_1) sample-(A_2-A_1) blank

Equation 2.7: Calculating ΔAD-fructose of raw and cooked vegetable samples.

$^{\Delta A}$D-fructose= (A_3-A_2) sample-(A_3-A_2) blank

Following this, the concentration of D-glucose and D-fructose was calculated according to the following formula:

Equation 2.8: Calculating the concentration of D-glucose and D-fructose of raw and cooked vegetable samples.

$$c = \frac{\mathrm{V\ x\ MW}}{\varepsilon\ \mathrm{x\ d\ x\ v}}\ \mathrm{x}\ \Delta \mathrm{A} \qquad \qquad [\mathrm{g/L}]$$

where:

c = concentration

d = light path [cm]

V =final volume

v = sample volume

MW =molecular weight of the substance assayed [g/mol]

ε = extinction coefficient of NADPH at 340 nm = 6300 [1 x mol^{-1} x cm^{-1}]

The results were multiplied by the dilution factor, which was 100 and the data was expressed as g/L.

2.3.7.3 DETERMINATION OF SUCROSE

In order to determine the sucrose concentration of the samples, 0.20 mL of β-fructosidase was placed into a cuvette labelled blank sucrose sample, while 0.20 mL of β-fructosidase and 0.10 mL of the prepared sample solution was placed into a cuvette labelled sucrose sample. Both cuvettes were mixed by gentle inversion, and were left to incubate for 5 min. Following this, 2 mL of distilled water, 0.10 mL of imidazole buffer and 0.10 mL of $NADP^+$/ATP was added to the blank sucrose sample, while 1.90 mL of distilled water, 0.10 mL of imidazole buffer and 0.10 mL of $NADP^+$/ATP was added to the sucrose sample. Both cuvettes were mixed and then placed into the UV/VIS spectrophotometer (Milton Roy Spectronic 1201, Pennsylvania, USA) which was set at 340 nm. The absorbances of the solutions (A_1) were documented. After 3 min, 0.02 mL of hexokinase and glucose-6-phosphate dehydrogenase suspension was added to both the blank and sucrose samples. The samples were mixed and the absorbances were noted for each of the solutions at the end of the reaction (A_2), which took approximately 5 min. The absorbance differences (A_2-A_1) for both blanks and samples were determined and from this, value of $^{\Delta A}$Sucrose was calculated according to the following equation:

Equation 2.9: Calculating ΔASucrose of raw and cooked vegetable samples.

ΔA total D-glucose= (A2-A1) sample – (A2-A1) blank

Following this, the concentration of sucrose was calculated as per Equation 2.6

2.3.8 ELECTRICAL CONDUCTIVITY MEASUREMENT

The electrical conductivity of organic and conventional raw tomato samples was determined using a method as outlined by Buret *et al.* (1983). Whole tomatoes were macerated for 1 min using a blender (Morphy Richards Limited, Mexborough, UK). The samples for testing were prepared by diluting 10 ml vegetable puree with 90 ml distilled water. The electrical conductivity was measured using a conductivity meter (Jenway 4330 Conductivity Meter, Staffordshire, UK) and the results were expressed in microSiemans (µS).

2.4 VOLATILE EMISSIONS STUDY

2.4.1 VOLATILE EMISSIONS ANALYSIS

Volatile analysis was carried out in quadruplicate on each of the organic and conventional vegetables, and was repeated on three separate occasions for each vegetable (n=12).

Volatile compounds from each of the raw and cooked vegetable samples were investigated using solid phase micro-extraction (SPME). Volatile analysis was carried out as described previously by Lonchamp *et al.*, (2009). Gas chromatography analysis was conducted on a Varian CP-3800 GC (JVA Analytical Ltd, Dublin, Ireland). Volatile compounds were absorbed by a CP- Sil 8 fused silica capillary column (length=30 m, diameter=25 mm, film thickness= 0.25 µm) (JVA Analytical Ltd, Dublin Ireland). Grade 5.0 helium was used as the carrier gas with a constant flow rate of 2 ml/min. The initial oven temperature was set at 30^{o}C and was maintained at this temperature for 5 min. The temperature was then increased to 250^{o}C at a rate of 5^{o}C per minute. The final temperature of 250^{o}C was maintained for 15 min. A Varian manual column quick switch selection valve (JVA Analytical Ltd, Dublin, Ireland) allowed the GC/MS to be configured so that the whole flow would be directed to the Mass Spectrometer (MS). The MS analysis was conducted using a Varian 2200 quadrupole MS (JVA Analytical Ltd, Dublin, Ireland). MS analysis of eluted compounds was carried out using an electron impact ionization technique. Electron impact mass spectra were recorded at 70 eV ionization energy in the 45 to 300 amu (atomic mass unit) mass range. Volatile extractions were performed manually. The absorptive coating material for the SPME fibre was polydimethylsiloxane (PDMS, 100 μm thickness) (Supelco, Bellefonte, PA, USA). The SPME fibre was conditioned in the GC/MS injection port, which was set at 250^{o}C, before commencing the analyses. The conditioning time used for the first injection of the day was 15 min, and thereafter, 5 min for all subsequent injections. Before extracting any volatile compounds an impermeable patch of PVC adhesive was applied to each pack of organic and conventional vegetables. The temperature of the organic and conventional vegetable samples was 4^{o}C. Prior to sampling, the centre of the pack was then punctured using a hypodermic needle. During sampling the SPME device was inserted into a pack and the fibre was exposed to the headspace for 5 min for volatile absorption. The volatiles were then desorbed for 3 min into the splitless injection port at 250^{o}C, after which the packs were resealed with another patch of impermeable PVC adhesive. Aroma volatiles were registered as chromatograph peaks with specific retention times from the capillary column of the gas chromatograph. These detected volatile compounds were defined by their retention times provided by the GC and its mass spectra. Retention times were compared with those of standard chemicals. Five standard chemicals were purchased from Sigma-Aldrich (Dublin, Ireland) to validate this method:

caryophyllene (CAS- No. 87-44-5), humulene (CAS- No. 6753-98-6), 1,4-dichlorobenzene (CAS-No. 95-50-1), cis-3-hexen-1-ol (CAS-No. 928-96-1) and trans-cinnameldehyde (CAS-No. 14371-10-9). Tentative identification of volatile compounds was also confirmed by the comparison of collected mass spectra with the reference spectra in the mass spectral NIST library (NIST, 1998) and comparing retention times with published papers using equivlant columns and methods (Pasqua *et al.,* 2003; Reid *et al.*, 2004; Kuo *et al.*, 2007; Lonchamp *et al.,* 2009; Serrano *et al.,* 2009). The compounds were identified with high probabilities when compared with standards from the NIST database (similarity coefficient or reverse similarity coefficient >85%). The aroma compounds were also reported in several volatile studies conducted on carrots, tomatoes and potatoes (Appendix A). Quantification of aroma volatiles was based on the areas of the peaks detected by the MS. The headspace concentration of an aroma compound was expressed as percent of the total peak area. The compounds were identified with high probabilities when compared with the standards from the NIST database.

2.5 SENSORY STUDY

2.5.1 ETHICAL CONSIDERATIONS

Prior to commencing this study, it was a requirement that ethical clearance be granted from DIT Research Ethics Committee before conducting any sensory tests using members of the public. It is believed that sensory testing has the potential to cause severe illness and even death, e.g. due to food poisoning or the ingestion of toxic ingredients. Therefore, it was essential all aspects of testing were considered to ensure all procedures and practices conformed to all legal and ethical requirements.

Declaration of research ethics and risk assessment documentation was sent to the DIT Research Ethics Committee, outlining procedures for the protection of sensory panellists, safety of sample ingredients, sample preparation and test protocol. The project was granted ethical clearance, subject to individuals being fully informed of the project (Appendix B) and completing consent forms (Appendix C).

2.5.2 SENSORY PANEL

Sensory analysis evaluations were performed using a trained panel and an untrained consumer panel. The recruitment criteria (Appendix D) required that both groups of panellists were:

1. Regular consumers of the produce being tested.
2. In good health
3. Non-smokers.
4. Willing to participate in sensory testing.

With particular reference to the trained panel personnel, it was a requirement that all potential trained panel members would be:

1. Able to pass flavour acuity tests.
2. Willing to commit to training and participate in sensory evaluation sessions on a regular basis.

Once individuals agreed to participate in the sensory studies, they were subjected to a series of screening tests (Odour Recognition Tests, Basic Taste Tests, and Texture Tests) to determine their level of skill and suitability (Appendix E). Individuals were selected on the basis of successfully passing standardized tests for aroma, texture and taste sensitivity.

2.5.3 SENSORY TRAINING

The sensory training sessions were conducted over a period of three months, which consisted of a total of 12 weekly thirty minute meetings. Sensory training sessions were delivered according to the guidelines set out in ISO 8586-1 (ISO, 1993). The panel also had previous sensory analysis experience regarding vegetable produce, in particular tomatoes and carrots.

Panel members were introduced to the sensory attributes, the terminology used to describe them, and the scales used to indicate the intensity. A range of reference samples for appearance, aroma, texture and taste attributes were presented to the panel members to show representative intensity differences (Appendix F).

Tests were repeated to enable the panel members to learn by repetition. Special attention was paid to ensuring panel members handled samples correctly. The importance of adhering to test procedures was stressed. Panel members were also told of the importance of disregarding personal preferences and concentrating on the detection of differences.

2.5.4 TRAINED PANEL

The experimental design for all three vegetables tested was the same as previously described in Section 2.3. Sensory evaluation of the raw carrots, steamed carrots, raw potatoes, and baked potatoes were performed by a trained panel of 10 judges (3 male, 7 female). For the raw tomato samples, sensory analysis was performed using a trained panel, consisting of 14 judges (9 female, 5 male). The heated tomato samples were evaluated by a panel of 10 judges (3 males and 7 females). Sensory attributes for all vegetables were selected from those previously reported in the literature (Rosenfeld *et al*., 1997; Haglund *et al.,* 1999; Thybo and Martens, 2000; Montouto-Graña *et al*., 2002; Stommel *et al.*, 2005; Meilgaard *et al*., 2007). The assessors worked in a single booth under defined conditions of 22^{o}C and white light. The sensory score cards were delivered using Compusense five (Version 4.4; Compusense Inc., Guelph, Ontario, Canada).

For the carrot evaluations, approximately 20 min before sensory analysis, the raw carrots were removed from the refrigerator and were transferred into white polystyrene cups (112g) with lids. The steamed carrots (80^{o}C) were presented in white polystyrene cups directly to the panel after cooking. For the analysis of the potato samples, the assessors were presented with a whole raw potato and whole baked potatoes (84^{o}C). Both the raw and baked samples were served on white paper plates. Whole tomato samples were served on white paper plates to the panel. While, 30 g of cooked organic tomato macerate (80^{o}C) and 30 g of cooked conventional tomato macerate (80^{o}C) were served in white plastic cups with lids.

All samples were coded with 3-digit random numbers and were presented in a randomised order to the panel. The assessors recorded their results on nine-point line scales for the carrot and potato samples, while eight-point line scales were utilized in the tomato study. Assessors were instructed to rinse their mouth with water between samples. The data was collected and analysed using Compusense five.

2.5.5 CONSUMER PANEL

Consumer panels were carried out on raw carrots and tomatoes, as well as baked potatoes. Individuals were selected on the basis of being regular consumers of vegetables. Panellists were purposely not told that they would be evaluating organic and conventional vegetables until they had completed scoring. This was done to eliminate the possibility of any potential bias that may have occurred had the panellists been informed of the nature of the trial. The panellists worked in a single booth under defined conditions of 22^{o}C and white light. All samples were coded with 3-digit random numbers and were presented in a randomised order to the panel. The panellists were required to cleanse their palates with water in between samples.

For the carrot and potato consumer studies, panellists were required to participate in acceptance tests and a paired preference test. Seventy-five consumers participated in the sensory evaluation of organic and conventional carrots. While, eighty consumers participated in the sensory evaluation of organic and conventional baked potatoes. For the acceptance tests, consumers were instructed to evaluate the colour, aroma, texture and taste acceptability of the vegetables on a 9-point hedonic scale, where 9= “like extremely” and 1= “dislike extremely”. The serving order of the vegetables was completely randomised. For the paired preference test, panellists received two samples in simultaneous presentation, half in the order A-B, the other half B-A. Samples were pre-coded with three digit random numbers. The subjects were asked to identify the preferred sample. The subjects are forced to make a choice.

Consumer sensory evaluation on the tomato samples was made up of two different elements: a triangle test and a paired preference test. A total of 72 consumers participated in this study. The triangle test was conducted according to the guidelines set out in ISO 4120:2004 (ISO, 2004). The subjects were presented with three samples and were advised that two of the samples were identical and one was different. 108 organic cherry vine tomato samples and 108 conventional cherry vine tomato samples were prepared to make 72 sample sets that were distributed at random among the subjects using 12 each of the combinations ABB, BAA, ABB, BBA, ABA and BAB. The subjects were asked to taste each sample from left to right and select the odd sample. The subjects were forced to make a decision. Following this, the panellists were required to participate in the paired preference test.

2.6 STATISTICAL ANALYSIS

All physicochemical and sensory data was recorded as means and ±standard deviations and was analysed using S.P.S.S 15 for Windows (S.P.S.S Inc, Chicago, Illinois, USA). Independent t-tests and one-way analysis of variance (ANOVA) were conducted to test for any significant differences between the raw organic and conventional vegetables, and between the cooked organic and conventional vegetables. Differences were considered significant at the 5% significant level. Where significant effects were found, the least significant difference test (LSD) was used to locate any significant differences between the means.

The results of the paired preference tests were analysed using binomial probability and the frequency procedure was used to determine the number of consumers who correctly identified the odd sample in the triangle test.

CHAPTER 3

3.1 GENERAL INTRODUCTION

Organically farmed foods have seen a significant rise in popularity in Ireland, such that the market for organic produce in Ireland has almost doubled since 2006 (Bord Bia, 2009a). The popularity of organic vegetables is attributed to the widespread belief that they are better tasting compared to conventionally produced vegetables (Bourn and Prescott, 2002; Magkos *et al.*, 2006; Winter and Davis, 2006; IFOAM, 2009). Aside from a better taste, it is also claimed that organically farmed vegetables have better colour, aroma and texture properties (The New Ecologist, 2010).

Vegetable quality is often assessed objectively, by means of physical and chemical analyses. Colour, firmness and flavour are the principle sensory parameters which affect the consumer's perception of vegetable quality (Pardo *et al.*, 2000; Thybo *et al*., 2005; Szymczak *et al.*, 2007). Consumers evaluate the acceptability of a food by its visual characteristics, such as size and colour (Hutchings, 1999). Colour is a particularly important sensory characteristic for vegetables, since colour is the first parameter which is assessed by the consumer (López-Camelo and Gómez, 2004; Kreutzmann *et al*., 2008). Texture is another important sensory parameter which plays a major part in a consumer's decision to purchase one vegetable over another. While, vegetable taste is of great importance to the consumer (Bruhn *et al*., 1991). The desirable flavour of vegetables is generally the result of a complex interaction between sugars and acids found in the vegetable.

The hypothesis of this study is that when compared to conventional vegetables, organically farmed vegetables, have a physicochemical composition which confers superior sensory properties. The objectives were to determine if the different growing systems affect the physicochemical components of organic and conventional carrots, potatoes and tomatoes either before or after cooking.

This will be investigated by minimising variability caused by cultivar, geographical location, climatic conditions and pre- and postharvest handling practices.

3.2 A COMPARISON OF THE PHYSICOCHEMICAL PROPERTIES OF ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING

3.2.1 SIZE VALUES OF ORGANIC AND CONVENTIONAL RAW CARROTS

Carrot appearance is characterised by size, shape and colour attributes. No significant differences were observed between the organic and conventional carrots for any of the size and shape parameters studied.

Eskin (1989) reported that the optimum temperature range which carrots develop best at, is between 16-21^{o}C, as temperatures exceeding 21^{o}C will result in shorter more stubby carrots, while temperatures below 16^{o}C yield longer and more slender carrots.

Mean temperatures recorded in counties Offaly and Wexford during the 2008 growing season (May-October) were 12.4^{o}C and 12.6^{o}C respectively (Met Éireann, 2009). Both the organic and conventional carrots were long, slender and cylindrical in shape with a *C*-value close to 1.0 (Table 3.1).

Table 3.1 Physicochemical components of organic and conventional raw carrots

Parameters	Organic	Conventional
Weight (g)	92.8 ± 13.8^{a}	85.8 ± 13.8^{a}
Length (cm)	15.5 ± 1.6^{a}	15.7 ± 1.9^{a}
Diameter (cm)	2.9 ± 0.3^{a}	2.8 ± 0.2^{a}
C-value	0.9 ± 0.1^{a}	0.9 ± 0.2^{a}
L*	65.2 ± 1.1^{a}	65.4 ± 1.3^{a}
a*	36.4 ± 1.0^{a}	35.9 ± 1.3^{a}
b*	35.7 ± 1.5^{a}	35.0 ± 1.8^{a}
Chroma	51.0 ± 1.4^{a}	50.1 ± 1.7^{a}
Hue Angle	44.4 ± 1.2^{a}	44.3 ± 1.7^{a}
Dry Matter (%)	12.2 ± 1.0^{a}	12.4 ± 0.8^{a}
Max. Puncture Force (N)	47.5 ± 1.7^{a}	46.9 ± 1.6^{a}
Sucrose (g/100g FW)	3.0 ± 0.3^{a}	3.0 ± 0.4^{a}
Glucose (g/100g FW)	1.8 ± 0.2^{a}	1.8 ± 0.2^{a}
Fructose (g/100g FW)	1.6 ± 0.2^{a}	1.6 ± 0.2^{a}
^{o}Brix	7.6 ± 0.5^{a}	7.5 ± 0.4^{a}
pH	6.0 ± 0.1^{a}	6.0 ± 0.1^{a}

Data are the mean values (± standard deviation) of organic and conventional raw carrots. Values bearing different superscripts are significantly different ($p\leq0.05$).

Table 3.2 Physicochemical components of organic and conventional steamed carrots.

Parameters	Organic	Conventional
L*	56.2 ± 0.9^{a}	56.3 ± 0.9^{a}
a*	29.6 ± 1.3^{a}	29.2 ± 1.5^{a}
b*	47.0 ± 1.2^{a}	47.4 ± 1.2^{a}
Chroma	58.8 ± 1.8^{a}	55.7 ± 1.3^{a}
Hue Angle	57.1 ± 1.7^{a}	58.4 ± 1.4^{a}
Dry Matter (%)	9.0 ± 0.8^{a}	8.7 ± 1.1^{a}
Max. Puncture Force (N)	4.3 ± 0.4^{a}	4.2 ± 0.4^{a}
Sucrose (g/100g FW)	2.4 ± 0.4^{a}	2.3 ± 0.3^{a}
Glucose (g/100g FW)	1.4 ± 0.2^{a}	1.3 ± 0.2^{a}
Fructose (g/100g FW)	1.1 ± 0.1^{a}	1.2 ± 0.2^{a}
^{o}Brix	4.5 ± 0.4^{a}	4.5 ± 0.4^{a}
pH	5.9 ± 0.1^{a}	5.9 ± 0.1^{a}

Data are the mean values (± standard deviation) of organic and conventional steamed carrots. Values bearing different superscripts are significantly different ($p\leq0.05$).

3.2.2 Colour values of organic and conventional carrots before and after steaming

A comparison between the organic and conventional raw carrot (Table 3.1), and between the organic and conventional steamed carrots (Table 3.2) showed no significant differences for the CIE L*, a*, b*, chroma and hue angle colour parameters. It was reported that excessive nitrogen fertilisation can result in a reduction in the amount of carotene produced in carrots and consequently, a loss in colour (Kader, 2002). However, in this study there was very little difference in the nitrogen fertilisation rates between the two growing systems. According to Statutory Instrument (2009), the organic carrots had 22.5 kg N ha^{-1} available to them, while 20 kg N ha^{-1} was available to the conventional carrot crop.

3.2.3 DRY MATTER VALUES OF ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING

No significant differences for percentage dry matter content were observed between the organic and conventional raw carrots, or between the organic and conventional steamed carrots (Table 3.1 and Table 3.2). The percentage of dry matter contained in the organic and conventional carrots was notably reduced after steaming. The cooked organic and conventional carrot samples had a significantly ($p \leq 0.05$) lower percentage of dry matter (17% and 18% lower respectively) than their equivalent raw carrot samples. These findings are in agreement with Nyman *et al.* (2005) who reported a 24% loss in the dry matter content of carrots after boiling. Additionally, Svanberg *et al.* (1997) found that the dry matter content of fresh carrots (14.5%) and stored carrots (18%) decreased significantly after boiling. De Belie *et al.* (2002) also reported that dry matter content of boiled carrots decreased linearly with cooking time. It had been previously reported by Magkos *et al.* (2003) that some organically grown crops have a higher dry matter content than conventionally grown crops. Although, this appears though only to be related, to crops grown above ground, such as spinach, lettuce and cabbage (Schuphan, 1974; Bourn, 1994;

Fjelkner-Modig *et al.*, 2000). On the contrary, for root vegetables and tubers, there is no strong evidence to suggest organic vegetables have higher dry matter content than their conventional counterparts (Schuphan, 1974; Termine *et al.*, 1987).

3.2.4 TEXTURE VALUES OF ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING

A comparison between the organic and conventional raw carrots, and between the organic and conventional steamed carrots showed no significant differences were apparent for texture. In addition to its affect on carrot size and colour, nitrogen fertilisation, can also have a considerable affect on the dry matter and texture of vegetables. It was reported that crops which were treated with high amounts of nitrogen (>100 kg N ha^{-1}) resulted in less firm vegetables (Hogstad *et al.* 1997). The similarities between the rates of nitrogen fertilisation applied to the crops and climatic conditions at both farms showed there was very little difference in the growing conditions for the organic and conventional carrots.

3.2.5 SUGAR CONTENT AND ^{O}BRIX VALUES OF ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING

Sugar plays an extremely important role in carrot flavour (Suojala, 2000). The main types of sugar that contribute to sweet carrot taste are sucrose, glucose and fructose (Varming *et al.*, 2004). A comparison between the organic and conventional raw carrots (Table 3.1), and between the organic and conventional cooked carrots (Table 3.2) found no significant difference for sucrose, glucose and fructose content or ^{o}Brix. However, the steamed organic and conventional carrot samples had less sucrose (22% and 23% respectively), glucose

(13% and 16% respectively) and fructose (19% and 16% respectively) than the raw samples ($p \leq 0.05$). This was attributed to the sugars leaching into the water on steaming. These results are in agreement with the findings of Svanberg *et al.* (1997). It was reported by Baardseth *et al*. (1995) that climatic conditions, such as exposure to rainfall and sunshine can significantly affect the sugar content of carrots. In a study conducted by Hogstad *et al*. (1997), it was reported that carrots which were exposed to total precipitation levels of 186mm (June-September 1989) and total sunshine hours of 937 (June-September 1989) contained more sucrose than those cultivated with higher total precipitation levels of 528mm (June-September 1990) and less total sunshine hours of 877 (June-September 1990). In this study, mean monthly rainfall amounts of 87.9mm±54.6 and 113.9mm±45.3, and mean monthly hours of sunshine were 130.3±34.1 and 148.7±30.9 were recorded in counties Offaly and Wexford respectively. No significant differences were observed between the mean precipitation levels, nor for the mean number of hours sunshine at each location. This may explain why there was no significant difference reported for the sugar content between the organically farmed and conventionally produced carrots.

3.2.6 ACIDITY VALUES OF ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING

No significant differences were observed between the organic and conventional raw carrots, and between the organic and conventional steamed carrots for pH values (Table 3.1 and Table 3.2). This would suggest that both the type of growing system and method of cooking had no effect on the acidity values of either type of carrot. The findings of Hogstad *et al*. (1997) concur with these results.

3.2.7 SUMMARY OF CARROT RESULTS

The results showed while different growing systems were used, they did not cause any significant differences in the physicochemical composition of the organic and conventional carrots, whether raw or steamed.

3.3 A COMPARISON OF THE PHYSICOCHEMICAL PROPERTIES OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING

3.3.1 SIZE VALUES OF ORGANIC AND CONVENTIONAL RAW POTATOES

No statistical differences were observed for any of the size parameters between the organic and conventional potato samples (Table 3.3).

Table 3.3 Physicochemical components of organic and conventional raw potatoes

Parameters	Organic	Conventional
Weight (g)	118.0 ± 26.3^{a}	116.6 ± 24.0^{a}
Length (cm)	8.3 ± 1.4^{a}	8.0 ± 1.3^{a}
Diameter (cm)	6.4 ± 0.7^{a}	6.2 ± 0.8^{a}
External L*	73.7 ± 2.5^{a}	74.2 ± 2.0^{a}
External a*	5.1 ± 0.7^{a}	5.0 ± 0.6^{a}
External b*	31.1 ± 1.6^{a}	31.3 ± 1.2^{a}
External Chroma	31.5 ± 1.6^{a}	31.7 ± 1.2^{a}
External Hue Angle	80.6 ± 1.3^{a}	80.9 ± 1.2^{a}
Internal L*	71.9 ± 1.7^{a}	72.1 ± 1.6^{a}
Internal a*	-0.2 ± 0.1^{a}	-0.12 ± 0.1^{a}
Internal b*	22.3 ± 0.7^{a}	22.5 ± 0.8^{a}
Internal Chroma	22.3 ± 0.7^{a}	22.5 ± 0.8^{a}
Internal Hue Angle	90.6 ± 0.3^{a}	90.5 ± 0.3^{a}
Dry Matter (%)	21.8 ± 0.9^{a}	20.1 ± 0.8^{b}
Max. Puncture Force (N)	32.1 ± 1.6^{a}	30.4 ± 1.4^{b}
Sucrose (g/100g FW)	0.9 ± 0.1^{a}	$0.9+0.1^{a}$
Glucose (g/100g FW)	0.9 ± 0.1^{a}	0.9 ± 0.1^{a}
Fructose (g/100g FW)	0.7 ± 0.1^{a}	0.7 ± 0.1^{a}
^{o}Brix	4.1 ± 0.5^{a}	4.2 ± 0.5^{a}
pH	5.7 ± 0.0^{a}	5.8 ± 0.0^{a}

Data are the mean values (± standard deviation) of organic and conventional raw potatoes. Values bearing different superscripts are significantly different ($p \leq 0.05$).

Table 3.4 Physicochemical components of organic and conventional baked potatoes.

Parameters	Organic	Conventional
External L*	56.1 ± 2.0^{a}	55.5 ± 1.7^{a}
External a*	9.1 ± 0.7^{a}	9.4 ± 0.7^{a}
External b*	33.0 ± 1.2^{a}	33.1 ± 1.2^{a}
External Chroma	34.3 ± 1.2^{a}	34.4 ± 1.2^{a}
External Hue Angle	74.6 ± 1.2^{a}	74.1 ± 1.1^{a}
Internal L*	77.3 ± 1.8^{a}	77.5 ± 1.3^{a}
Internal a*	-3.6 ± 0.3^{a}	-3.5 ± 0.2^{a}
Internal b*	18.9 ± 0.7^{a}	19.1 ± 0.5^{a}
Internal Chroma	19.3 ± 0.7^{a}	19.3 ± 0.6^{a}
Internal Hue Angle	100.9 ± 0.7^{a}	100.4 ± 0.5^{a}
Dry Matter (%)	23.9 ± 1.3^{a}	22.3 ± 1.3^{b}
Max. Puncture Force (N)	2.2 ± 0.5^{a}	1.6 ± 0.4^{b}
Sucrose (g/100g FW)	$0.8+0.1^{a}$	$0.8+0.1^{a}$
Glucose (g/100g FW)	0.8 ± 0.1^{a}	0.7 ± 0.1^{a}
Fructose (g/100g FW)	0.6 ± 0.1^{a}	0.6 ± 0.1^{a}
^{o}Brix	3.4 ± 0.6^{a}	3.5 ± 0.6^{a}
pH	5.8 ± 0.0^{a}	5.8 ± 0.0^{a}

Data are the mean values (± standard deviation) of organic and conventional baked potatoes. Values bearing different superscripts are significantly different ($p \leq 0.05$).

3.3.2 Colour values of organic and conventional potatoes before and after baking

The results of the colour analysis for the organic and conventional raw potato samples are presented in Table 3.3. A comparison between the organic and conventional raw potato skin colour found no significant difference for Hunter L*, a* b*, chroma and hue values. This would suggest that the cultivation method had very little effect on the skin colour of the potato. As with the skin colour, no significant differences were recorded for L*, a*, b*, chroma and hue colour values between the flesh colour of the organic and conventional raw potato samples. For the baked potatoes, no statistically significant differences were observed between the external colour and between the internal colour of the organic and conventional potato samples for any of the colour parameters (Table 3.4).

3.3.3 DRY MATTER VALUES OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING

The dry matter content of a potato usually ranges between 18-26% (Burton, 1989) and it is an incredibly important parameter of potato quality, as it influences the effects of cooking on sensory attributes, in particular texture (Taylor *et al.*, 2007). A comparison between the raw organic and conventional potato samples found a significant difference ($p \leq 0.05$) for dry matter content (Table 3.3). The raw conventional potatoes had a lower dry matter content ($p \leq 0.05$) than the raw organic potatoes. These results are in agreement with the findings of previous studies conducted on the dry matter content of organic and conventional potatoes (Hajšlová *et al*, 2005; Maggio *et al.*, 2008). The low dry matter content of the raw conventional potatoes may have occurred due to the rate of nitrogen fertilisation. O'Beirne and Cassidy (1990) conducted a study on the effects of nitrogen fertiliser on the dry matter content of potatoes and reported that the dry matter content of potatoes was significantly reduced by fertilising crops with quantities of nitrogen with values in the range of 150kg ha^{-1} or higher. Burton (1989) reported that the application of phosphorus and potassium do not appear to affect the dry matter content of potatoes. In this study the organic crop was fertilised with a composted farmyard manure at a rate of 25000kg ha^{-1} annually. One tonne of organic farmyard manure contains 4.5kg N and 1.2kg P (Statutory Instrument, 2009). Therefore, this organic farmyard manure supplied the crop with 113kg N ha^{-1} and 30kg P ha^{-1}. While the conventional crop was fertilised with a synthetic N-P-K fertiliser at a rate of (10-10-20) 1235kg ha^{-1} annually. This would mean that 124kg N ha^{-1}, 124kg P ha^{-1} and 248kg K ha^{-1} was incorporated into the soil of the conventional crop. However, according to Statutory Instrument No. 101 of 2009, approximately 25% of the nitrogen and 100% of the phosphorus is available from the organic farmyard manure, whereas 100% of the nitrogen and 100% of the phosphorus is available from the chemical fertiliser. Therefore, this means that only 28kg N ha^{-1} and 30kg P ha^{-1} was available to the organic potato crop, while 124kg N ha^{-1} and 124kg P ha^{-1} was available to the conventional potato crop. This shows that the conventional potato crop was exposed to higher quantities of nitrogen and phosphorus per hectare compared to the organic potato crop (an additional of 96kg N ha^{-1} and 94kg P ha^{-1} respectively). This may have caused the conventional potatoes to have less dry matter than the organic potatoes. According to Burke (2003) the application of large quantities of nitrogen increases the size of the canopy during the early growth phase of the potato, which in turn diverts dry matter into the production of excess leaf and stem to the detriment of the tuber. In addition to this, regardless of the type of nitrogen fertiliser (inorganic, organic manures), plants use nitrogen only in the form of nitrate (NO_3-) and ammonium (NH_4+). According to Herrera *et al.* (1999) nitrogen containing compounds are broken down into free ammonium, which is converted into ammonia and ammonia salts. Microorganisms “fix nitrogen” by breaking down ammonia into nitrite (NO_2-) and then to nitrate (NO_3-). Nitrate (NO_3-) and ammonium (NH_4+) are dissolved in the soil water and taken up by the plant. Nutrients from organic fertilisers are released more slowly and steadily to the plant (Montagu and Goh, 1990), whereas synthetic chemical fertilisers offer more readily available sources of nitrogen, to accelerate plant growth (Faller and Fialho, 2009). The effect of baking on the dry matter content of the organic and conventional potatoes can be found in Table 3.4**.** A statistically significant difference ($p \leq 0.05$) was documented between the organic and conventional baked potatoes for dry matter content, with the conventional potato having a lower dry matter content.

3.3.4 TEXTURE VALUES OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING

Maximum puncture force values for raw organic and conventional potato samples are shown in Table 3.3. A comparison between the organic and conventional raw potatoes found a significant difference ($p \leq 0.05$) for maximum puncture force. The conventional potatoes were significantly softer ($p \leq 0.05$) than the organic potatoes. This result was attributed to the dry matter content which was significantly higher in the organic potatoes. Dry matter is of particular importance with regard to texture. Gopal and Khurana (2006) reported that dry matter is generally correlated with texture. A comparison between the baked organic potato and the baked conventional potato showed a statistically significant difference ($p \leq 0.05$) for the maximum puncture force (Table 3.4). The conventional baked potato was softer than the organic baked potato.

3.3.5 SUGAR CONTENT AND ^{O}BRIX VALUES OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING

No significant difference was observed between the organic and conventional raw potato, and between the organic and conventional baked potato samples for sucrose, fructose, glucose, total sugar content and ^{o}Brix. The sugar content of potatoes is largely influenced by agronomic practices. Maggio *et al.* (2008) found that irrigation improved accumulation of starch in potato tuber, but it had the opposite effect on sucrose. In the aforementioned study it was reported that nitrogen over fertilisation significantly ($\geq$200kg N ha^{-1}) reduced the biosynthesis of sucrose, fructose and glucose. Although there was a considerable difference in the amounts of nitrogen applied to each potato crop in this study, a reduction in the synthesis of sugars in tubers may only be evident at much higher rates of nitrogen application. Baking also resulted in a slight loss in the amounts of sugars found in the organic and conventional baked potatoes. This loss of sugar was attributed to the loss of moisture during the baking process.

3.3.6 ACIDITY VALUES OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING

No significant difference was recorded between the organic and conventional raw potato samples, nor between the organic and conventional baked potatoes for pH (Table 3.3 and Table 3.4). This would suggest that the growing systems used had little effect on the pH value for the tested potatoes.

3.3.7 SUMMARY OF POTATO RESULTS

In summary, no statistical differences were found for the size, colour, sugar content and pH values of the raw and baked organic or conventional potatoes. However, the organic potato (raw or baked) had a higher percentage of dry matter when compared to the corresponding conventional potato (raw or baked). This higher percentage dry matter could be correlated to the greater firmness of the organic potatoes. The growing conditions, particularly the rate of application and uptake of nitrogen fertiliser by the potato plant, may have had a significant effect on potato texture.

3.4 A COMPARISON OF THE PHYSICOCHEMICAL PROPERTIES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING

3.4.1 SIZE VALUES OF ORGANIC AND CONVENTIONAL WHOLE TOMATOES

A comparison between the organic and conventional whole tomatoes found no significant difference for the longitudinal (stem scar to blossom end) and the cross-sectional (transverse diameter) dimensions of the tomato (Table 3.5).

Table 3.5 Physicochemical components of organic and conventional raw tomatoes.

Parameters	Organic	Conventional
Longitudinal Diameter (mm)	37.4 ± 1.2^{a}	37.3 ± 1.1^{a}
Cross Sectional Diameter (mm)	40.9 ± 2.0^{a}	40.5 ± 1.7^{a}
L*	40.0 ± 1.0^{a}	39.9 ± 0.9^{a}
a*	29.5 ± 1.0^{a}	29.8 ± 1.0^{a}
b*	23.7 ± 1.0^{a}	23.5 ± 1.0^{a}
a*/b*	1.3 ± 0.1^{a}	1.3 ± 0.1^{a}
Dry Matter (%)	6.6 ± 0.9^{a}	6.6 ± 0.9^{a}
Max. Puncture Force (N)	22.4 ± 1.9^{a}	22.0 ± 1.6^{a}
Glucose (g/100g FW)	2.0 ± 1.2^{a}	2.2 ± 1.5^{b}
Fructose (g/100g FW)	2.6 ± 0.8^{a}	3.2 ± 0.8^{b}
^{o}Brix	6.9 ± 0.4^{a}	7.3 ± 0.4^{b}
pH	4.3 ± 0.1^{a}	4.3 ± 0.1^{a}

Data are the mean values (± standard deviation) of organic and conventional raw tomatoes. Values bearing different superscripts are significantly different ($p \leq 0.05$).

Table 3.6 Physicochemical components of organic and conventional heated tomatoes.

Parameters	Organic	Conventional
L*	28.2 ± 0.9^{a}	28.1 ± 0.8^{a}
a*	15.3 ± 0.7^{a}	15.3 ± 0.5^{a}
b*	26.5 ± 1.2^{a}	26.6 ± 1.4^{a}
Chroma	30.7 ± 1.2^{a}	30.7 ± 1.2^{a}
Hue Angle	60.0 ± 1.4^{a}	60.1 ± 1.5^{a}
Dry Matter (%)	6.5 ± 0.9^{a}	6.5 ± 1.5^{a}
Viscosity (Hz)	0.4 ± 0.7^{a}	0.4 ± 0.7^{a}
Glucose (g/100g FW)	2.0 ± 1.2^{a}	2.2 ± 1.5^{b}
Fructose (g/100g FW)	2.6 ± 0.8^{a}	3.2 ± 0.8^{b}
^{o}Brix	6.5 ± 0.4^{a}	7.5 ± 0.4^{b}
pH	4.2 ± 0.2^{a}	4.2 ± 0.2^{a}

Data are the mean values (± standard deviation) of organic and conventional heated tomatoes. Values bearing different superscripts are significantly different ($p \leq 0.05$).

3.4.2 COLOUR VALUES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING

The colour values for the organic and conventional raw tomatoes are shown in Table 3.5. A comparison between the organic and conventional whole tomatoes showed no significant differences for the CIE L*, a*, b*, a*/b* colour parameters. This would indicate that both organic and conventional tomato had a similar colour and were at the same stage of ripeness at the time of examination. The mean values recorded for L*, a* and b* were similar to those reported in the literature for tomatoes ripened on the vine (Arias *et al.*, 2000).

For heating purposes, the tomatoes were required to be macerated before heating. A comparison between the organic and conventional heated tomato macerates (80^oC) showed no significant differences for any of the colour parameters (Table 3.6).

Temperature can affect the colour of tomatoes. Koskitalo and Ormond (1972) reported that low growing temperatures can reduce lycopene synthesis, which would have a significant effect on colour. However, Grierson and Kader (1986) found that tomatoes exposed to temperatures greater than 30^oC resulted in irregular ripening. This was attributed to the inhibition of lycopene synthesis at temperatures above 30^oC, as well as the inhibition of carotenoid synthesis at 40^oC or higher.

In this study, mean temperatures of 23^oC and 21^oC were recorded in the organic and conventional greenhouses respectively, which would indicate that temperatures were sufficient to facilitate lycopene synthesis, and would therefore not affect colour.

3.4.3 DRY MATTER VALUES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING

Mean values recorded for the percentage dry matter content of the organic and conventional tomatoes were similar to those documented in the literature (Thybo *et al*., 2006; Barrett *et al*., 2007). A comparison between organic and conventional whole tomatoes (Table 3.5), and between the organic and conventional heated tomato macerates (Table 3.6) showed no significant differences for the dry matter content.

3.4.4 TEXTURE VALUES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING

No significant difference for texture was observed between the organic and conventional whole tomatoes (Table 3.5), or between the organic and conventional heated tomato macerates (Table 3.6). This would suggest that both tomatoes had the same degree of firmness. Thybo *et al.* (2005) also found no significant differences between tomatoes cultivated in soil and those that were grown hydroponically for texture analysis.

3.4.5 SUGAR CONTENT AND ^{o}BRIX VALUES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING

Significant differences ($p \leq 0.05$) were observed between the raw organic and conventional tomatoes, and between the heated organic and conventional tomato macerates for sugar content and ^{o}Brix. Both raw and heated conventional tomato macerates had a greater sugar content and a higher ^{o}Brix ($p \leq 0.05$) than both the corresponding raw and heated organic tomato macerates. This was attributed to the effect of the nutrient solution given to the tomato plants. Sato *et al*. (2006) found that hydroponically produced tomatoes with treated with NaCl enriched nutrient solution at a rate of 5 dSm^{-1} were sweeter and more flavoursome than those treated with 1.4 dSm^{-1}. While, Claussen *et al*. (2006) also reported a significant increase in the sugar content of tomatoes treated with a salt enriched nutrient solution. In this study, a significant difference was reported for electrical conductivity with the conventional tomato samples having a higher value (895 µS) than the organic tomatoes (681 µS). Gormley and Egan (1984) reported that tomatoes with an electrical conductivity value of >800 µS generally have very good tomato fruit flavour, while tomatoes having an electrical conductivity value of <550 µS are considered as having a poor tomato fruit flavour. Sonneveld and Welles (1988) also supported this finding by stating that tomato fruit quality, in particular flavour was improved by increased electrical conductivity values. Petersen *et al.* (1998) reported that the levels of reducing sugars found in tomatoes were linearly correlated to the electrical conductivity of the nutrient solution between the ranges of 3-10 dSm^{-1}. Wu and Kubota (2008) also found that high electrical conductivity treatments increased the total soluble solids content of red ripe tomatoes compared to low electrical conductivity treatments. It was believed that the effect of electrical conductivity on the total soluble solids content was due to an osmotic effect, and a resulting reduced water flux to the tomato.

3.4.6 ACIDITY VALUES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER STEAMING

A comparison between organic and conventional raw tomato, and between both types of heated tomato macerate found no significant difference for pH value. This would suggest that neither the cultivation method nor heating had an effect on the pH of the tomato macerates in this study.

3.4.7 SUMMARY OF TOMATO RESULTS

The results of this study indicated there were differences in the physicochemical properties of the Irish grown organic and conventional tomatoes. The conventionally produced tomatoes contained significantly higher quantities of glucose and fructose, and had a higher ^{o}Brix value, whether raw or heated. The higher quantity of sugars (glucose and fructose) present in the conventional tomatoes may have been attributed to the nutrient solution given to the conventional tomato plants. The conventional tomatoes had a higher electrical conductivity value compared to the organic tomatoes. This would suggest that the conventional tomatoes were more flavoursome. No statistical differences were found between the organic and conventional tomato samples for colour, size, dry matter, firmness and pH values.

3.5 OVERALL SUMMARY OF RESULTS OF THE PHYSICOCHEMICAL QUALITY OF ORGANIC AND CONVENTIONAL VEGETABLES

Organic agricultural growing systems rely on crop rotations, farmyard manures, composting, mulches and biological pest control to maintain soil productivity and biodiversity, and to control pests. Whereas, conventional farmers apply synthetic chemical fertilisers, herbicides, insecticides, fungicides and pesticides to their crops to provide them with adequate, nutrition and to protect them from attack from pests and disease. Such practices are not permitted in organic agriculture.

In this study, the organic carrots were fertilised using a farmyard manure and the conventional carrots were treated with a synthetic fertiliser. While, the fertiliser inputs were different, the relative amounts of nitrogen applied to the organic and conventional carrot crops (22.5kg N ha^{-1} vs 20kg N ha^{-1}) were very similar. It was thought that the fact no significant differences were evident between the organic and conventional carrots for any of physicochemical parameters, may have been due to the fact there was very little difference in the amounts of nitrogen applied to either carrot crop (Table 3.7). In the case of the potatoes, the conventional potato crop was exposed to significantly higher quantities of N per hectare (124kg N ha^{-1}) compared to the organic potato crop (28kg N ha^{-1}). It is believed this may have caused the conventional potatoes to have less dry matter than the organic potatoes, which also affected the firmness of the potatoes (Table 3.7). This may imply that the application of high rates of nitrogen to a crop, may have a significant impact on dry matter content of the vegetable.

In the case of the tomatoes, the organic tomatoes were grown in brown earth soil and the conventional tomatoes were grown hydroponically on rockwool slabs. Growing vegetables hydroponically is not permitted in organic agriculture. Minor compositional differences were attributed to the salt enriched nutrient solution that was applied to the conventional tomato crop (Table 3.7).

In conclusion, while different growing systems were used, the effect on the physicochemical parameters of all three vegetables tested was not significant, with the exception of potato texture and the differences in sugar content observed between the organic and conventional tomatoes (Table 3.7). Contrary to what is publicised in the media or by organic advocates, the results of these tests indicate that organic carrots, potatoes and tomatoes do not have a physicochemical composition which confers superior sensory properties over conventional carrots, potatoes and tomatoes.

Table 3.7: Summary of significant physicochemical quality differences between organic and conventional vegetables.

Physicochemical Properties	**Raw Carrot** Organic v Conventional	**Cooked Carrot** Organic v Conventional	**Raw Potato** Organic v Conventional	**Cooked Potato** Organic v Conventional	**Raw Tomato** Organic v Conventional	**Cooked Tomato** Organic v Conventional
Size	N.S	N.S	N.S	N.S	N.S	N.S
Colour	N.S	N.S	N.S	N.S	N.S	N.S
Dry Matter	N.S	N.S	$p \leq 0.05$	$p \leq 0.05$	N.S	N.S
Texture	N.S	N.S	$p \leq 0.05$	$p \leq 0.05$	N.S	N.S
Sugar Content	N.S	N.S	N.S	N.S	$p \leq 0.05$	$p \leq 0.05$
°Brix	N.S	N.S	N.S	N.S	$p \leq 0.05$	$p \leq 0.05$
pH	N.S	N.S	N.S	N.S	N.S	N.S

N.S: Not Significant

CHAPTER 4

4.1 GENERAL INTRODUCTION

The flavour of organic and conventional vegetables has been the topic of considerable debate (Food Safety Authority of Ireland, 2008b). As a result, several studies have sought to determine whether significant differences truly exist between organic and conventional produce (Basker, 1992; Woese *et al*., 1997; Wszelaki *et al*., 2005; Zhao *et al*., 2007). However, there is still limited scientific evidence to support or refute the claim that organic food has superior sensory quality compared to conventional food (Bourn and Prescott, 2002; O'Rourke, 2008). Flavour is a important quality criteria of vegetables (Krumbein and Auerswald, 1998). The flavour of vegetables is generally attributed to aroma factors, detected by the nose, and taste factors detected by the tongue. Simply measuring colour, taste and texture properties of organic and conventional vegetables, by no means reflects the total sensory experience of the vegetables. The characteristic flavour of vegetables is largely attributed to their volatile composition (Petró-Turza, 1987; Maga, 1994; Krumbien *et al.,* 2004; Kalua *et al.,* 2007; Kreutzmann *et al.,* 2008). Therefore, to acquire knowledge of the compounds responsible for vegetable flavour and how they are influenced by cultivation systems, it is necessary to study the composition of volatiles present in the organic and conventional vegetables. The objectives of this study were to determine (1) the volatile flavour profiles of Irish grown organic and conventional carrots (cv. Nairobi), potatoes (cv. Orla) and tomatoes (cv. Amoroso) and (2) to identify any differences between the volatile profiles of the organic and conventional vegetables.

4.2 VOLATILE EMISSIONS FROM ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING

Twenty-nine raw organic and conventional carrot volatile compounds were detected and identified by comparison of their Mass Spectroscopy (MS) data with those of the NIST Database (Table 4.1). The main groups of volatile emissions observed in the raw and cooked volatile study were monoterpenes and sesquiterpenes.

Of the twenty-nine organic and conventional carrot volatile compounds detected, twenty were identified with very high probabilities (similarity coefficient or reverse similarity coefficient >85%). While, the remaining nine volatile compounds were recognised as having high probabilities (similarity coefficient or reverse similarity coefficient >75 %).

After steaming the organic and conventional carrots, only thirteen cooked organic and conventional carrot volatile compounds were detected and identified (Table 4.1). Of the thirteen cooked organic and conventional carrot volatile compounds that were detected, eleven were identified with very high probabilities (similarity coefficient or reverse similarity coefficient >85%). While, the remaining two volatile compounds were identified with high probabilities (similarity coefficient or reverse similarity coefficient >75 %).

Table 4.1: Aroma volatiles emitted from organic and conventional carrots, before (▲) and after steaming (●)

Retention Time (min)	**Volatile Compound**[b,c]	**Organic**		**Conventional**		**Odour Description**[d]
		Raw[a]	**Steamed**[a]	**Raw**[a]	**Steamed**[a]	
15.40	**β-pinene**	▲		▲		Fresh, Green
15.89	Sabinene	▲		▲		Fresh, Green
17.28	Limonene	▲		▲		Citrus, Terpy
17.74	α-pinene	▲		▲		Turpentine
18.08	***p*-cymene**	▲		▲		Carrot, Wood
18.53	**γ-terpinene**	▲	●	▲	●	Herbaceous
19.47	**Terpinolene**	▲	●	▲	●	Sweet Pine
24.81	**δ-elemene**	▲	●	▲	●	Woody
25.89	γ-cadiene	▲		▲		Woody
26.51	**β-elemene**	▲		▲		Herb, Wax
26.94	**Thujopsen**	▲		▲		Not Described
27.05	**isocaryophillene**	▲		▲		Not Described
27.17	**β –humulene**	▲		▲		Not Described
27.30	**α-bergamotene**	▲	●	▲	●	Wood, Warm
28.01	**Caryophyllene**	▲	●	▲	●	Terpy, Spicy
28.55	**Humulene**	▲	●	▲	●	Wood
28.78	β –himachalene	▲		▲		Herb, Wood
29.08	γ-muurolene	▲		▲		Herb, Woody
29.18	**Valencene**	▲	●	▲	●	Citrus
29.27	**β–cubene**	▲		▲		Not Described
29.46	**α –bisabolene**	▲		▲		Sweet

[a] Aroma compounds identified in organic and conventional carrots, before and after steaming are indicated with triangles and circles respectively.

[b] The compounds identified with very high probabilities are indicated in bold font (similarity coefficient or reverse similarity coefficient >85%).

[c] The compounds identified with high probabilities are indicated in normal font (similarity coefficient or reverse similarity coefficient >75%).

[d] Seifert and Buttery (1978), Burdock (2002), Kreutzmann *et al.* (2008) and Gutierrez *et al*. (2009)

Table 4.1 continued: Aroma volatiles emitted from organic and conventional carrots, before (▲) and after steaming (●)

Retention Time (min)	**Volatile Compound**[b,c]	**Organic**		**Conventional**		**Odour Description**[d]
		Raw[a]	**Steamed**[a]	**Raw**[a]	**Steamed**[a]	
30.89	**Cuparene**	▲		▲		Not Described
31.30	caryophyllene oxide	▲		▲		Citrus
31.60	**neryl acetate**	▲	●	▲	●	Sweet, Floral, Citrus
32.20	**phenyl benzoate**	▲	●	▲	●	Not Described
29.86	**α –longipinene**	▲	●	▲	●	Turpentine
30.21	α –patchoulene	▲	●	▲	●	Not Described
30.48	**α –himachalene**	▲	●	▲	●	Not Described
30.51	2,4-dimetylquinoline	▲	●	▲	●	Not Described

[a] Aroma compounds identified in organic and conventional carrots, before and after steaming are indicated with triangles and circles respectively.
[b] The compounds identified with very high probabilities are indicated in bold font (similarity coefficient or reverse similarity coefficient >85%).
[c] The compounds identified with high probabilities are indicated in normal font (similarity coefficient or reverse similarity coefficient >75%).
[d] Seifert and Buttery (1978), Burdock (2002), Kreutzmann *et al.* (2008) and Gutierrez *et al*. (2009)

4.2.1 RAW CARROT VOLATILES

In the case of organic and conventional carrots, this study showed the major monoterpenes were α-pinene, sabiene, β-pinene, γ-terpinene, terpinolene and limonene. The major sesquiterpenes were caryophyllene and humulene. Such terpenes impart the characteristic aroma to carrots and are considered to be the most important volatile compounds of carrots (Buttery *et al.*, 1968; Kjeldsen *et al.*, 2001; Cliffe-Byrnes and O’Beirne, 2007; Gutierrez *et al.*, 2009). Caryophyllene was the most abundant volatile compound in the organic and conventional carrots. The retention time was consistent with the internal standard and retention time as reported by Reid *et al.*, (2004) and Lonchamp *et al.* (2009). The conventional carrot contained a significantly higher percentage of caryophyllene compared to the organic carrot (Fig 4.1).

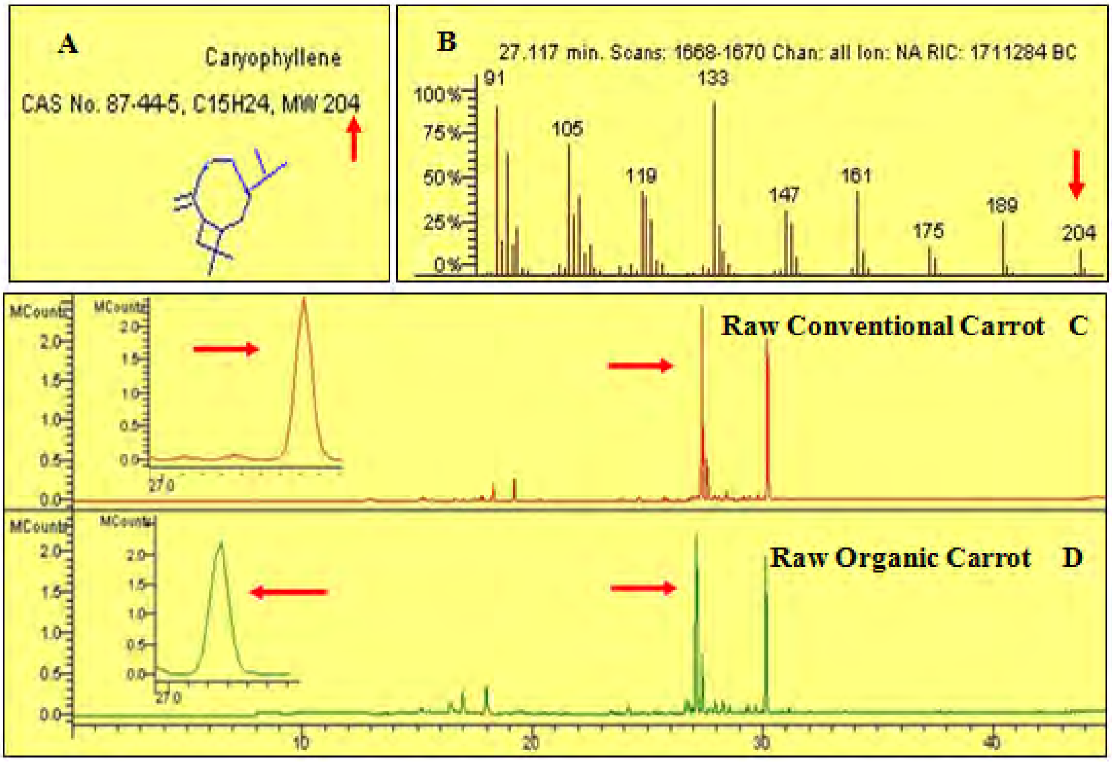


Fig. 4.1: Structure (A) and MS spectra (B) of caryophyllene identified in raw conventional (C) and organic carrots (D).

Caryophyllene is known to impart a spicy pine aroma (Burdock, 2002). Statistically significant differences ($p \leq 0.05$) in the levels of terpinolene were also noted, with the conventional carrot having a greater concentration of this monoterpene. Terpinolene is responsible for imparting a sweet pine aroma (Burdock, 2002). Sabiene and α-pinene were identified in both the organic and conventional carrot samples. Significant differences ($p \leq 0.05$) were observed between the organic and conventional carrot samples, for both of these aroma volatiles with the conventional carrots emitting significantly higher amounts of both volatile compounds. Sabiene is responsible for imparting a fresh green aroma, while α-pinene gives the carrot its characteristic bitter turpentine aroma. The aroma volatile γ-terpinene, was also found in both the organic and conventional carrots, but was found at a significantly higher concentration in the conventional carrots ($p \leq 0.05$). The retention time of this compound was similar to that of Kuo *et al.* (2007). This particular volatile is known to impart a green herbaceous aroma (Kreutzmann *et al*., 2008). All of these terpenes occur naturally in carrots. Although, it is believed the increased concentrations of these compounds detected in the conventional carrots may have been attributed to the insecticide and fungicides that were applied to the conventional crop. Many plant extracts and essential oils form part of the ingredients of insecticides because of their pleasant odour (Sköld et al., 2006) and their potential insect control properties (Kim *et al*., 2003). The widespread use of pesticides has drawn considerable negative publicity (insect resistance, toxicity to non target mammals, pesticide residues and environmental pollution). Public awareness of the possible risks of pesticide use has pressurised pesticide manufacturers into finding alternatives to replace synthetic chemicals. In recent years, research has focused on the use of plant oils as possible alternatives to synthetic chemical pesticides as they are more environmentally friendly (ElShafei *et al*., 2010). Plant oils have been found to have repellent and insecticidal properties (Abdelgaleil *et al.*, 2009).

The aroma volatiles humulene, limonene and *p*-cymene were all found in higher concentrations in the organically farmed carrots than the conventionally produced carrots ($p \leq 0.05$). Humulene is a monocyclic sesquiterpene, which is known to impart a woody aroma (Fig 4.2). The retention time for humulene was consistent with the internal standard and retention time as reported by Pasqua *et al*. (2003) and Reid *et al*. (2004).

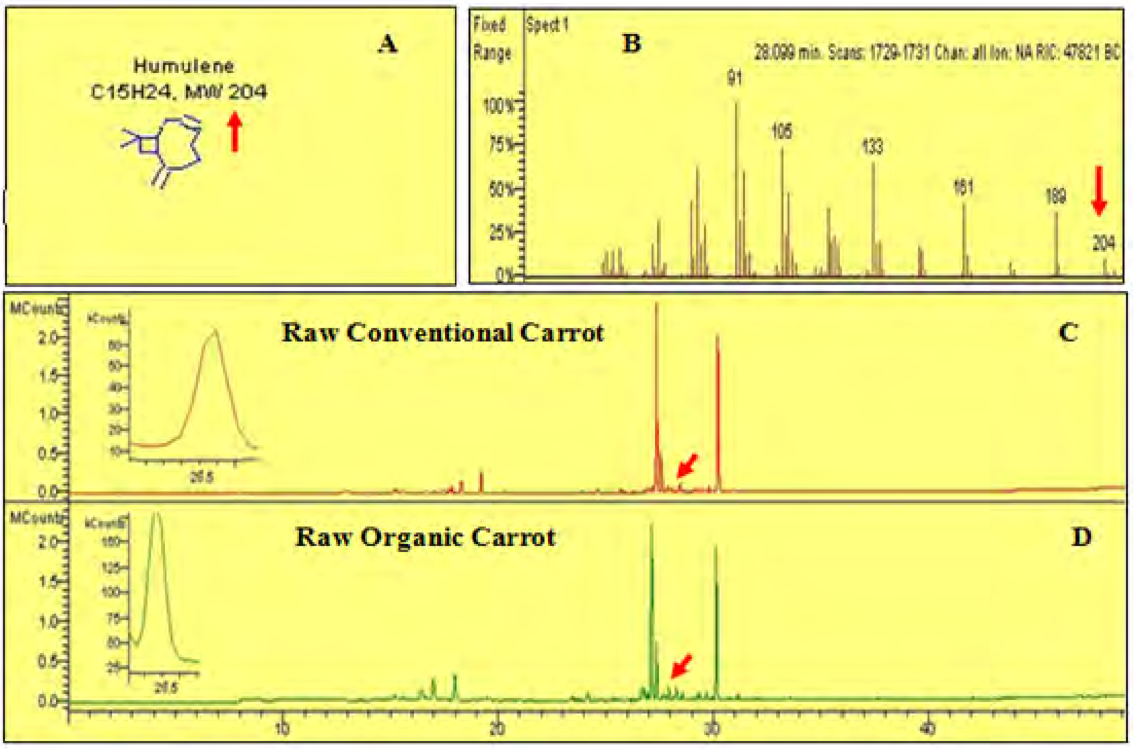


Fig. 4.2: Structure (A) and MS spectra (B) of humulene identified in raw conventional (C) and organic carrots (D).

Limonene is a monoterpene and in carrots, limonene is responsible for imparting a citrus pine aroma (Burdock, 2002). The retention time for limonene was similar to that of the retention time as documented Lonchamp *et al*. (2009). The aroma volatile *p*-cymene is an important contributor to fresh carrot aroma and is characterised as having a woody aroma. This aroma compound is synthesised from limonene (Martín-Luengo *et al*., 2008).

The functions of these terpenes are to protect the vegetable from potential predation, and to assist in the attraction of pollinators (Croteau *et al*., 2000). When plants are stressed from infection and/or predation, they respond with an increase in defensive chemicals (Matteson, 2000). Synthetic pesticides and insecticides are used to reduce plant stress. Therefore, it can be argued that natural toxin production is suppressed in the presence of synthetic chemical inputs, while induced in their absence, in order to maintain defensive integrity. Harborne (1990) reported physical damage caused by pests, can also lead to an increase in secondary metabolites that acts as precursors of natural defence toxins. Limonene has been reported to have antibiotic and antiprotozoal properties (Arruda *et al.*, 2009).

4.2.2 COOKED CARROT VOLATILES

Steaming altered the volatile profile of the organic and conventional carrots considerably (Table 4.1). The most important volatiles in the cooked organic and conventional carrot samples were α–patchoulene, caryophyllene, γ-terpinene and terpinolene. Several authors had previously reported that caryophyllene, γ-terpinene and terpinolene were the most important volatiles for cooked carrot flavour (Heatherbell and Wrolstad., 1971; Simon *et al*, 1980; Howard *et al*., 1995). In this study, steaming resulted in a significant increase ($p \leq 0.05$) in the volatile concentrations of γ-terpinene, terpinolene and α–patchoulene in the organic and conventional carrots. However, a significant reduction ($p \leq 0.05$) in the concentration of caryophyllene was observed in both the organic and conventional carrot samples. Steaming also resulted in significant volatile losses in organic and conventional carrot samples. Headspace analysis showed complete loss of many monoterpenes (β-pinene, sabiene, limonene, α-pinene, *p*-cymene) and sesquiterpenes (β-elemene, β-humulene, β-himachalene, β-cubene) in the steamed organic and conventional samples. These losses most likely occurred due to the leaching of compounds into the cooking liquid, evaporation of compounds into the atmosphere and/or degradation of enzymes during heat treatment (Alasalvar *et al*., 1999). These results are supported by the findings of Simon and Lindsay (1983) who reported a loss of 70-85% of the total terpenoids found in cooked carrots. While, Alasalvar *et al.* (1999) found that cooking resulted in losses of 89%, 93% and 96% in the total terpenoid content of fresh carrots after cooking for 10, 20 and 30 minutes respectively. Furthermore, Shamaila *et al.* (1996) documented that terpenes, in particular β-pinene, sabiene, limonene, β-myrcene, α-humulene and β-bisabolene decreased by 50% within 1 minute of blanching.

4.2.3 SUMMARY OF CARROT VOLATILE EMISSIONS BEFORE AND AFTER STEAMING

Concentrations of caryophyllene, terpinolene, sabiene, α-pinene and γ-terpinene were all significantly higher in the raw conventional carrots than the raw organic carrots. Limonene, *p*-cymene and humulene were detected in significantly greater quantities in the raw organic carrots when compared to the raw conventional carrots. Steaming resulted in significant increases in the concentrations of γ-terpinene, terpinolene and α–patchoulene in both the organic and conventional carrots. However, most of the terpenes (β-pinene, sabiene, limonene, α-pinene and *p*-cymene) found in both the organic and conventional raw carrots were lost after steaming.

4.3 VOLATILE EMISSIONS FROM ORGANIC AND CONVENTIONAL POTATOES AFTER BAKING

Seventeen baked organic potato volatiles and nineteen baked conventional potato volatile compounds were detected and identified by comparison of their Mass Spectroscopy (MS) data with those of the NIST Database (Table 4.2). The main groups of volatile emissions observed in the baked potato volatile study were ketones, acids, alcohols, benzenes and hydrocarbons.

Of the 17 organic potato volatile compounds detected, 8 were identified with very high probabilities (similarity coefficient or reverse similarity coefficient >85%). While, the remaining 9 volatile compounds were recognised as having high probabilities (similarity coefficient or reverse similarity coefficient >75 %). For the 19 conventional potato volatile compounds that were detected, 9 were identified with very high probabilities (similarity coefficient or reverse similarity coefficient >85%). While, the remaining 10 volatile compounds were acknowledged as having high probabilities (similarity coefficient or reverse similarity coefficient >75 %).

Table 4.2: Aroma volatiles emitted from organic and conventional baked potatoes (●)

Retention Time (min)	**Volatile Compound**[b,c]	**Organic Baked**[a]	**Conventional Baked**[a]	**Odour Description**[d]
16.79	1,4-dichlorobenzene		●	Fresh
16.85	**1,2-dichlorobenzene**		●	Pleasant Aromatic
17.93	butyrolactone	●	●	Sweet, Caramel
21.07	2-decanone	●	●	Floral, Fruity
21.79	octanoic acid	●	●	Faintly Fruity
23.99	**benzoic acid**	●	●	Slightly Balsamic
24.12	nonanoic acid	●	●	Fatty
25.76	**valencene**	●	●	Fruity
26.33	**4-octanolide**	●	●	Sweet Herbaceous
26.93	2-butanol	●	●	Green Oily
27.14	2-methylcoumaran	●	●	Not Described
28.57	**2,6-ditertbutyl-benzoquinone**	●	●	Musty
28.73	**biphenyl**	●	●	Floral
29.53	butylated hydroxytoulene	●	●	Phenolic
30.50	**2,6-bis(1,1-dimethyl)-4-(1-oxopropyl)phenol**	●	●	Not Described
32.57	**2-acetylphenol**	●	●	Sweet Floral
36.08	**phenyl benzoate**	●	●	Not Described
37.95	iso-palmitate	●	●	Not Described
44.07	di-n-octyl phthalate	●	●	Not Described

[a] Aroma compounds identified in organic and conventional potatoes after baking are indicated with circles.
[b] The compounds identified with very high probabilities are indicated in bold font (similarity coefficient or reverse similarity coefficient >85%).
[c] The compounds identified with high probabilities are indicated in normal font (similarity coefficient or reverse similarity coefficient >75%).
[d] Burdock (2002) and Lonchamp *et al*. (2009)

4.3.1 BAKED POTATO VOLATILES

Seventeen of the aroma volatiles identified were common to both the organic and conventional baked potatoes (Table 4.2). Four of these compounds were previously reported as cooked potato volatile compounds, namely octanoic acid, nonanoic acid, 2-acetylphenol, 2-butanol and biphenyl (Maga, 1994; Burdock, 2002). Following an extensive and thorough literature search on potato volatiles, there was no documented reporting for the other 11 volatile compounds found. Differences were observed between the organic and conventional baked potatoes for the concentrations of biphenyl and 2-butanol. Both of these compounds were found in significantly higher concentrations in the organic potatoes when compared to the conventional baked potatoes. Biphenyl has a characteristic floral aroma, while 2-butanol imparts a green fatty odour (Burdock, 2002).

However, a comparison between the baked organic and conventional potatoes found no significant difference ($p>0.05$) for the volatile concentrations of octanoic acid, nonanoic acid and benzoic acid. Octanoic acid is responsible for imparting a faintly fruity aroma, benzoic acids emits a faintly balsamic odour, while nonanoic acid is characterised by a fatty coconut aroma (Burdock, 2002). Two ketones (butyrolactone and 2-decanone) were also detected and identified in the headspace of the organic and conventional baked potatoes. No significant differences were documented between the organic and conventional baked potato for butyrolactone and 2-decanone. These volatiles emit a sweet and floral aroma. The only terpene identified in the organic and conventional baked potato samples was valencene. The retention time was consistent with Lonchamp *et al.* (2009). This aroma volatile is a sesquiterpene, derived from the mevalonic pathway. It has a distinctive floral aroma. Several authors had previously reported that terpenoids, in particular monoterpenes are greatly affected by cooking methods, times and temperatures (Simon and Lindsay, 1983; Shamaila *et al*., 1996; Alasalvar *et al*., 1999). Another aroma compound that was detected in both the organic and conventional baked potatotes was 2-methylcoumaran. This particular volatile is believed to be derived from p-coumaric acid, a product of the phenylpropanoid acid pathway (Bassil *et al*., 2005). Two volatile chlorinated compounds 1,4-dichlorobenzene and 1,2-dichlorobenzene (Fig 4.3) were identified specifically in the baked conventional potato samples. Retention times were consistent with the internal standard and the retention times as reported by Lonchamp *et al.* (2009). It is believed that these two compounds may have been derived from the chemical fungicides applied to the crop (Lonchamp, 2006).

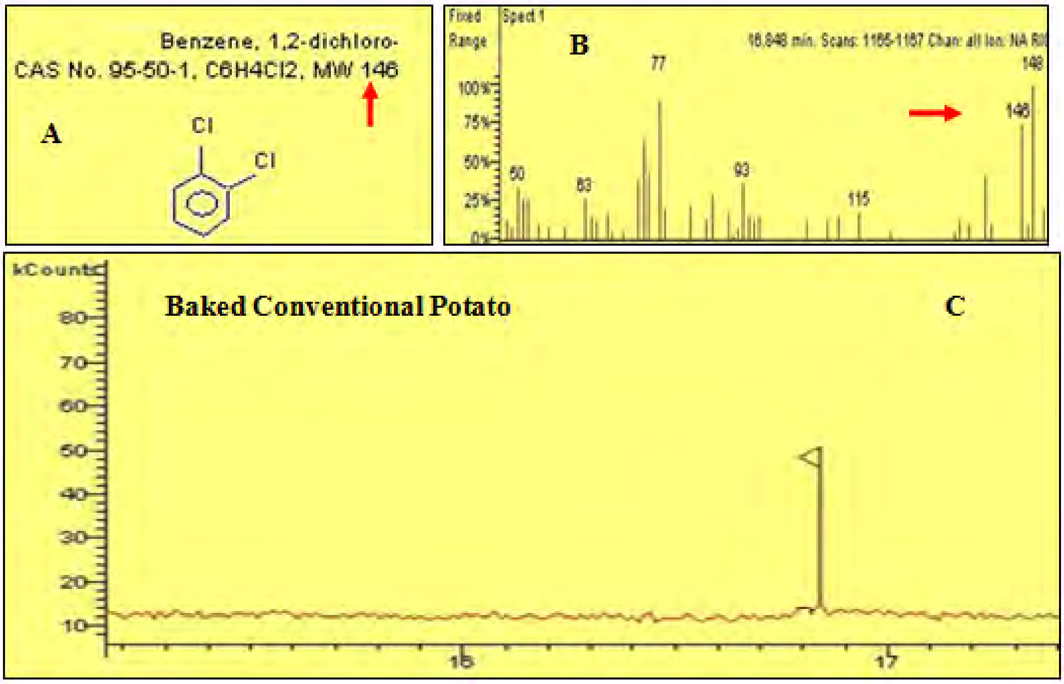


Fig. 4.3: Structure (A) and MS spectra (B) of identified 1,2-dichlorobenzene in baked conventional potatoes (C)

4.3.2 SUMMARY OF POTATO VOLATILE EMISSIONS AFTER BAKING

Differences were observed between the organic and conventional baked potatoes for the concentrations of 2-butanol and biphenyl, with the organic potatoes having higher quantities of both volatile compounds ($p \leq 0.05$). The aroma compounds 1,4-dichlorobenzene and 1,2-dichlorobenzene were specific to the conventional baked potatoes.

4.4 VOLATILE EMISSIONS FROM ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING

Thirty-six raw organic tomato volatiles and thirty-five raw conventional tomato volatile compounds were detected and identified by comparison of their Mass Spectroscopy (MS) data with those of the NIST Database (Table 4.3). Of the thirty-six organic tomato volatile compounds detected, fifteen were identified with very high probabilities (similarity coefficient or reverse similarity coefficient >85%). While, the remaining twenty-one volatile compounds were recognised as having high probabilities (similarity coefficient or reverse similarity coefficient >75 %). For the thirty-five conventional tomato volatile compounds detected, fifteen were identified with very high probabilities (similarity coefficient or reverse similarity coefficient >85%). The remaining twenty volatile compounds were acknowledged as having high probabilities (similarity coefficient or reverse similarity coefficient >75 %). After heating both the organic and conventional tomatoes, thirty-six organic tomato volatiles and thirty-five conventional tomato volatile compounds were detected and identified (Table 4.3). Of the thirty-six organic volatile compounds that were detected, sixteen were identified with very high probabilities (similarity coefficient or reverse similarity coefficient >85%). While, the remaining twenty volatile compounds were identified with high probabilities (similarity coefficient or reverse similarity coefficient >75 %). For the thirty-five conventional tomato volatile compounds detected, fifteen were identified with very high probabilities (similarity coefficient or reverse similarity coefficient >85%). The remaining twenty volatile compounds were found to have high probabilities (similarity coefficient or reverse similarity coefficient >75 %).

Table 4.3: Aroma volatiles emitted from organic and conventional tomatoes, before (▲) and after heating (●)

Retention Time (min)	Volatile Compound[b,c]	Organic		Conventional		Odour Description[d]
		Raw[a]	Heated[a]	Raw[a]	Heated[a]	
8.68	**Furfural**	▲	●	▲	●	Sweet Fruity
8.78	**2-furanmethanol**	▲	●	▲	●	Caramel
9.53	2-cyclohexen-1-one	▲		▲		Acetone
9.59	***trans*-2-hexenal**		●		●	Green
9.82	2H-pyran-2-one	▲	●	▲	●	Not Described
9.86	2-cyclopentene,1-4 dione	▲	●	▲	●	Sour
10.87	methyl pyruvate				●	Not Described
10.94	*cis*-3-hexene	▲		▲		Green
11.50	1,2-cyclopentandione	▲	●	▲	●	Ethereal
11.73	**α-pinene**	▲		▲		Turpentine
11.78	Acetylfuran		●			Sweet
11.91	**2(5H)-furanone**		●		●	Sweet
12.21	dihydro-3-methylene-2,5,furandione	▲		▲		Not Described
12.60	3- methyl-2,5-furandione	▲	●	▲	●	Not Described
12.75	5-methyl-2(5H)-furanone		●		●	Sweet, Spicy
12.89	**5-methyl-2-furancarboxaldehyde**	▲	●	▲	●	Sweet, Woody,
13.34	**β-pinene**	▲		▲		Turpentine
13.96	2-carene	▲				Turpentine
14.11	**Terpinolene**	▲		▲		Sweet, Pine

[a] Aroma compounds identified in organic and conventional tomatoes before and after heating are indicated with triangles and circles respectively.

[b] The compounds identified with very high probabilities are indicated in bold font (similarity coefficient or reverse similarity coefficient >85%).

[c] The compounds identified with high probabilities are indicated in normal font (similarity coefficient or reverse similarity coefficient >75%).

[d] Burdock (2002), Lonchamp *et al*. (2009)

Table 4.3 continued: Aroma volatiles emitted from organic and conventional tomatoes, before (▲) and after heating (●)

Retention Time (min)	Volatile Compound[b,c]	Organic		Conventional		Odour Description[d]
		Raw[a]	Heated[a]	Raw[a]	Heated[a]	
14.32	4H-pyran-4-one		●		●	Not Described
15.81	2-methyl-3-oxo,ethyl ester, butanoic acid	▲				Not Described
15.05	2,2-diethyl-3-methyl-oxazolidine		●		●	Not Described
15.28	**β-phellandrene**	▲		▲		Fresh Citrus
15.56	**1H-pyrrole-2-carboxaldehyde**		●		●	Sweet Cooked Ethereal
15.68	2,4-heptadienal, (*E,E*)	▲				Green Fatty
15.97	**3-methyl-1,2-cyclopentandione**		●			Not Described
16.44	2,5-dimethyl-4 hydroxy-3(2H)-furanone	▲	●	▲	●	Sweet Caramel
17.29	**1-(1H-pyrrol-2-yl)-ethanone**		●		●	Not Described
17.52	2-furancarboxylic acid		●		●	Odourless
18.81	**Maltol**	▲	●	▲	●	Warm, Sweet
18.89	N-methyl-N-nitroso-2-propanamine	▲	●	▲	●	Not Described
19.86	2,3-dihydro-3,5-dihydroxy-6methyl-4H-pyran-4-one	▲	●	▲	●	Sweet, Caramel

[a] Aroma compounds identified in organic and conventional tomatoes before and after heating are indicated with triangles and circles respectively.

[b] The compounds identified with very high probabilities are indicated in bold font (similarity coefficient or reverse similarity coefficient >85%).

[c] The compounds identified with high probabilities are indicated in normal font (similarity coefficient or reverse similarity coefficient >75%).

[d] Burdock (2002), Lonchamp *et al*. (2009)

Table 4.3 continued: Aroma volatiles emitted from organic and conventional tomatoes, before (▲) and after heating (●)

Retention Time (min)	**Volatile Compound**[b,c]	**Organic**		**Conventional**		**Odour Description**[d]
		Raw[a]	**Heated**[a]	**Raw**[a]	**Heated**[a]	
20.38	**5-hydroxymaltol**	▲	●	▲	●	Sweet
20.59	**benzoic Acid**	▲	●	▲	●	Faint Balsamic
20.97	Dodecanal	▲		▲		Citrus, Green
21.41	**1,2-benzenediol**		●		●	Not Described
21.41	**ethanol-2-phenoxy**	▲	●	▲	●	Rose, Honey
21.88	**5-hydroxymethyl-(2-furancarboxaldehyde)**	▲	●	▲	●	Brown, Sweet
22.49	2,5-pyrrolidene		●			Not Described
22.95	glycerol acetate		●		●	Not Described
23.85	3-methyl-2,3-dihydro-benzofuran	▲	●	▲	●	Not Described
25.83	1,3-diisocyanato-2-methyl-benzene	▲	●	▲	●	Musty
26.03	**2,4-diisocyanato-1-methyl-benzene**	▲	●	▲	●	Musty
26.53	*o*-chloroanisole			▲		Not Described
27.72	1-(2-hydroxyphenyl)-ethanone	▲		▲		Sweet, Floral, Herbaceous
28.52	geranyl acetone	▲	●	▲	●	Pleasant Floral
29.40	Pentadecanal			▲		Fresh, Waxy

[a] Aroma compounds identified in organic and conventional tomatoes before and after heating are indicated with triangles and circles respectively.

[b] The compounds identified with very high probabilities are indicated in bold font (similarity coefficient or reverse similarity coefficient >85%).

[c] The compounds identified with high probabilities are indicated in normal font (similarity coefficient or reverse similarity coefficient >75%).

[d] Burdock (2002), Lonchamp *et al.* (2009)

Table 4.3 continued: Aroma volatiles emitted from organic and conventional tomatoes, before (▲) and after heating (●)

Retention Time (min)	Volatile Compound[b,c]	Organic Raw[a]	Organic Heated[a]	Conventional Raw[a]	Conventional Heated[a]	Odour Description[d]
30.04	2,4-bis(1,1-dimethylethyl)-phenol		●		●	Not Described
32.51	decyl ester, decanoic acid	▲		▲		Fresh, Sweet, Fatty
35.99	***1-heptadecanol***	▲		▲		Not Described
38.86	Piperidine				●	Heavy, Sweet
40.35	n-hexadonic acid	▲	●	▲	●	Pungent, Rancid
41.13	2-(1-(4-hydroxyphenyl)-1-methylethyl)-phenol	▲	●	▲	●	Not Described
43.79	**bis-phenol**	▲	●	▲	●	Not Described

[a] Aroma compounds identified in organic and conventional tomatoes before and after heating are indicated with triangles and circles respectively.
[b] The compounds identified with very high probabilities are indicated in bold font (similarity coefficient or reverse similarity coefficient >85%).
[c] The compounds identified with high probabilities are indicated in normal font (similarity coefficient or reverse similarity coefficient >75%).
[d]Burdock (2002), Lonchamp *et al.* (2009)

4.4.1 RAW TOMATO VOLATILES

Three aldehydes (furfural; 5-methyl-2-furancarboxaldehyde and 5-hydroxymethyl-2-furancarboxaldehyde) were detected in the volatile profiles of both the raw organic and conventional tomatoes. Two of the volatiles identified were previously detected in tomato sauce. These were reported as furfural (Petró-Turza, 1987; Burdock, 2002) and 5-methyl-2-furancarboxaldehyde. The aroma compounds furfural, 5-methyl-2-furancarboxaldehyde and 5-hydroxymethyl-2-furancarboxaldehyde are responsible for imparting sweet caramel nuances (Burdock, 2002). Another aldehyde identified and detected in both the organic and conventional raw tomato samples was dodecanal. This volatile compound was previously reported in the literature by Kazeniac and Hall (1970).

The aroma compound (*E,E*)-2,4-heptadienal was specific to the raw organic tomato. The retention time was similar to that of Serrano *et al.* (2009). This volatile compound is responsible for emitting a fresh green floral citrus odour. It has been previously documented in the literature by Kalua *et al*. (2007) and (Lee *et al.*, 2005). It is thought the seaweed fertiliser may have been responsible for this compound. It has been reported that (*E,E*)-2,4-heptadienal has been detected in the volatile profiles of edible seaweeds (Sugisawa et al., 1990; Kajiwara et al., 1996). The alkene *cis*-3-hexene was detected and identified in both the organic and conventional tomatoes. This volatile is believed to be derived from the aldehyde compound *cis*-3-hexenal. *Cis*-3-hexenal is known to have a characteristic fresh green aroma (Burdock, 2002). It has been previously reported in the literature by several authors (Boukobza and Taylor, 2002; Krumbien *et al.*, 2004; Thybo *et al.*, 2006). This volatile is formed upon the maceration of the fruit (Prestage *et al.*, 1999). The maceration of the tissue results in the degradation of lipids to fatty acids (Galliard *et al.*, 1977). The detection rates for *cis*-3-hexenal in the raw organic and raw conventional samples were lower than expected and maybe explained by the method of processing. In this GC-MS study, the tomatoes were sliced in half and packed in OPP+ bags prior to carrying out headspace analysis. It has been documented that tissue disruption results in major changes in the volatile profiles of tomatoes (Buttery and Ling, 1993). Kazeniac and Hall (1970) reported that if sliced tomatoes rather than macerated tomatoes were studied, the quantities of aldehydes would be lower, in contrast to the blended samples. Two other alkene volatile compounds which were identified and detected in the organic and conventional tomatoes were 1,3-diisocyanato-2-methyl-benzene and 2,4-diisocyanato-1-methyl-benzene. The retention time for 2,4-diisocyanato-1-methyl-benzene. was consistent with Lonchamp *et al.* (2009). These compounds are responsible for emitting a musty aroma. Additionally, the alkane aroma compound 2-methylcoumaran was also detected in both the organic and conventional tomatoes. This particular volatile is believed to be derived from p-coumaric acid, a product of phenylpropanoid acid pathway (Bassil *et al.*, 2005). Four monoterpenes (α-pinene; β-pinene; terpinolene and β-phellandrene) were common to both the organic and conventional raw tomatoes. All four of these monoterpenes had been previously documented in the literature as volatile components of tomato aroma (Petró-Turza, 1987; Wang *et al.*, 2001). While, the aroma volatile 2-carene was specific to the organic tomatoes in this study (Fig 4.4).

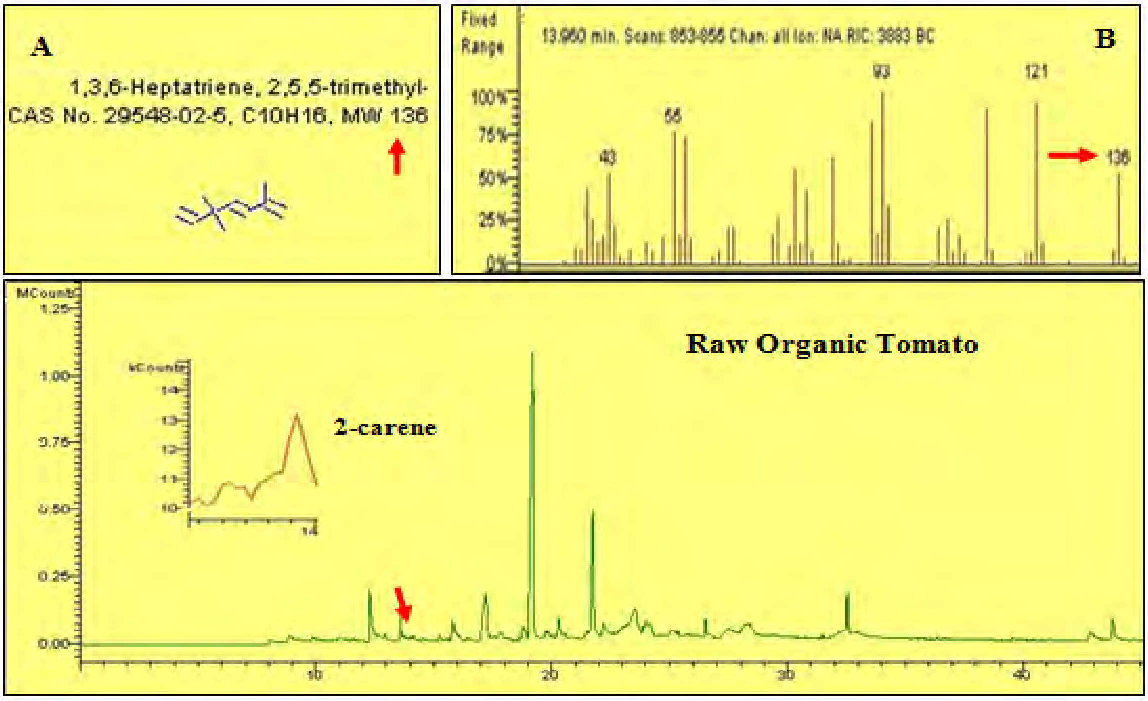


Fig. 4.4: Structure (A) and MS spectra (B) of 2-carene identified in organic tomatoes (C).

This volatile had previously been identified in the fruit (Petró-Turza, 1987) and leaves (Buttery *et al*., 1987; Wang *et al*., 2001) of the tomato fruit. In addition to this the aroma volatile 2-methyl-3-oxo, ethyl ester, butanoic acid was found in the organic samples. It is thought these compounds may have been derived as a defence mechanism for protection against pests and disease. The aldehyde pentadecanal was specific to the raw conventional tomato. This compound was previously reported to be found in tomatoes by Petro- Turza (1987). Interestingly, a study by Hurd *et al.* (2004) revealed that pentadecanal was one of the chemical pheromones secreted by prey mantid. It is believed predatory insects (*Macrolophus caliginosus*) used in the conventional greenhouse may have emitted the same compound.

Four pyranones (2H-pyran-2-one; 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one; maltol and 5-hydroxymaltol) were observed in both the raw organic and conventional tomato samples. The conventional tomato samples had higher levels ($p \leq 0.05$) of all four pyranones. The aroma compound 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one was the most abundant compound in both the raw organic and conventional tomato samples (Fig 4.5). This particular aroma volatile is formed as a result of a chemical reaction between fructose and β-alanine (Nishibori and Kawakishi, 1990). The conventional tomatoes contained significantly higher quantities ($p \leq 0.05$) of fructose than the organic tomatoes. This may have resulted in an increase in the concentration of 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one in the conventional tomato samples. It had also been documented that the aroma compounds maltol and 5-hydroxymaltol are synthesised as a result of the thermal degradation of 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one (Ledel, 1990; Kim and Baltes, 1996).

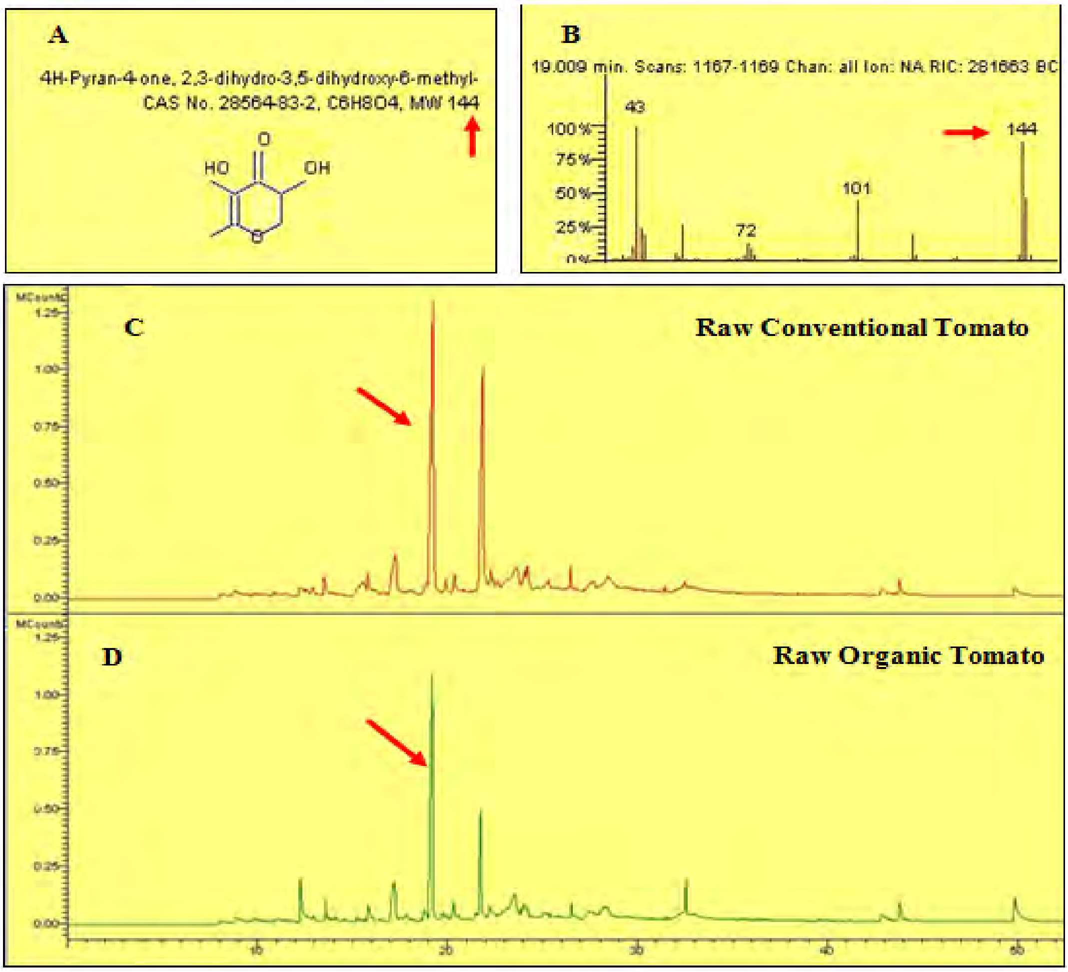


Fig. 4.5: Structure (A) and MS spectra (B) of 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one detected in conventional (C) and organic (D) tomatoes

Shinoda *et al*., (2005) also found that fructose is essential for the production of 5-hydroxymaltol in orange juice. Higher fructose levels may also have stimulated an increase in the levels of 5-hydroxymaltol and maltol in the conventional tomato samples.

The aroma volatile 2,5-dimethyl-4 hydroxy-3(2H)-furanone was detected in both the organic and conventional raw tomatoes. No significant difference was observed between the organic and conventional samples for this volatile. The aroma compound 2,5-dimethyl-4 hydroxy-3(2H)-furanone was first detected by Rodin *et al*. (1965) in pineapples. Since then it has been identified in strawberries (Re *et al.*, 1973), raspberries (Honkanen *et al.*, 1980) and tomatoes (Buttery *et al.*, 1995). This particular aroma volatile is responsible for imparting strong sweet caramel nuances (Krumbien and Auerswald, 1998).

4.4.2 COOKED TOMATO VOLATILES

Heating had a considerable effect on the volatile profiles of the organic and conventional tomatoes. Significant volatile losses in both the organic and conventional heated tomato samples were recorded. Headspace analysis showed complete loss of many terpenes (β-pinene, α-pinene, 2-carene, terpinolene, β-phellandrene) and aldehydes (2,4-heptadienal, (*E*,*E*); dodecanal) in the heated organic and conventional samples. These losses may have occurred due to the evaporation of compounds into the atmosphere and/or degradation of enzymes during heat treatment.

The aroma volatile cis-3-hexene was not detected in the heated tomato samples, but the aroma volatile *trans*-2-hexenal was observed. In a study conducted by Kazeniac and Hall (1970), it was reported that the aroma compound *cis*-3-hexenal was unstable when heated, such that it was isomerised to *trans*-2-hexenal upon heating. They proposed that heat converted *cis*-3-hexenal to *trans*-2-hexenal. This might explain the loss of the aroma compound *cis*-3-hexene in both types of heated tomato samples.

The aroma compound 5-ethyl-2(*5H*)-furanone was previously identified in tomatoes by Buttery and Ling (1993). This compound is a homologue of angelica lactone (Buttery and Takeoka, 2004). In this study, the β–form of angelica lactone, 5-methyl-2(*5H*)-furanone was found in both the heated organic and conventional tomato samples. This aroma compound is of particular interest because its formation is reportedly a result of the degradation of the aroma compound *cis*-3-hexenal (Buttery and Takeoka, 2004). They reported that this compound was formed when solutions of purified *cis*-3-hexenal had contact with air for a couple of hours.

A comparison between the heated organic and conventional tomato samples revealed differences for the aroma compounds 2,3-dihydro-3,5-dihydroxy-6-methy-4H-pyran-4-one and 5-hydroxymethyl-2-furancarboxaldehyde. The heated conventional tomato samples contained significantly higher quantities of both compounds.

Similarly, greater concentrations of the volatile compounds 2,5-dimethyl-4 hydroxy-3(2H)-furanone, 2-furanmenthanol and 2-pyran-2-one were found in the conventional tomato sample. The difference in the amounts of these volatile compounds was attributed to the effect of heating on the sugar content of the conventional tomatoes. GC-MS data indicated that cooking resulted in a significant increase ($p \leq 0.05$) in the volatile concentrations of some aldehydes (furfural; 5-methyl-2-furancarboxaldehyde and 5-hydroxymethyl-2-furancarboxaldehyde), furanone (2,5-dimethyl-4 hydroxy-3(2H)-furanone) and pyranones (2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one; maltol and 5-hydroxymaltol). All heated tomato samples had significantly higher concentrations of these aroma compounds compared to the raw tomato samples. This increase was attributed to the thermal degradation of sugars and the Maillard reaction (Ames *et al*., 1999). In addition to this, the aroma compound 4H-pyran-4-one was only found in the heated organic and conventional samples. A comparison between both heated tomato samples found a significant difference for 4H-pyran-4-one, with the conventional sample having a higher concentration than the organic sample. This was again attributed to the differences in the sugar content of both types of tomato. Heating also synthesised nitrogen containing heterocyclic compounds (1H-pyrrole-2-carboxaldehyde; piperidine; 2,5-pyrrolidene and 1-(1H-pyrrol-2-yl)-ethanone), and oxygen containing heterocyclic compounds (acetylfuran and 2,2-diethyl-3-methyl-oxazolidine). The aroma compound piperidine was specific to heated conventional tomatoes, while 2-acetylfuran was only found in heated organic tomato samples

4.4.3 SUMMARY OF TOMATO VOLATILE EMISSIONS BEFORE AND AFTER HEATING

The aroma compounds (*E*,*E*)-2,4-heptadienal, 2-carene and 2-methyl-3-oxo, ethyl ester, butanoic acid were only detected in the raw organic tomatoes, whereas the volatile compounds *o*-chloroanisole and pentadecanal were specific to the raw conventional tomatoes. Concentrations of the volatiles 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one, maltol and 5-hydroxymaltol were significantly higher in the raw conventional tomatoes compared to the raw organic tomatoes. Heating resulted in significant increases in the concentrations of the volatile compounds furanmenthanol, 2H-pyran-2-one, 2,5-dimethyl-4 hydroxy-3(2H)-furanone, 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one and 5-methyl-2-furancarboxaldehyde in both types of tomato macerate. The heated conventional tomato samples had greater concentrations of all five volatile compounds compared to the heated organic tomato samples. Heating resulted in the formation of new compounds in the organic and conventional samples, such as trans-2-hexenal, 2(5H)-furanone, 5-methyl-2(5H)-furanone, 4H-pyran-4-one, 2,2-diethyl-3-methyl-oxazolidine, 1H-pyrrole-2-carboxaldehyde, 1-(1H-pyrrol-2-yl)-ethanone and 2 furancarboxylic acid. The aroma compounds methyl pyruvate and piperdine were specific to the heated conventional tomato samples. The aroma volatiles acetylfuran, 3-methyl-1,2-

cyclopentandione and 2,5-pyrrolidene were common to the heated organic tomato macerates. Significant losses in some terpenoids (α-pinene, β-pinene and β-phellandrene), alkenes (*cis*-3-hexene), ketones (2-cyclohexen-1-one, dihydro-3-methylene-2,5,furandione) and aldehydes (dodecanal and 1-heptadecanal) were also observed in both heated organic and conventional tomato macerates.

4.5 OVERALL SUMMARY OF RESULTS OF THE VOLATILE EMISSIONS OF ORGANIC AND CONVENTIONAL VEGETABLES

Much of the information derived from food is obtained through our sense of smell (Blake, 2004). Thus, the sensory quality of vegetables is largely dependent on their volatile composition (Petró-Turza, 1987; Oruna-Concha *et al*., 2002; Kreutzmann *et al.,* 2008). Volatile compounds directly affect the sensorial quality of vegetables, the aroma of which is formed by a complex group of chemical substances, namely aldehydes, alcohols, ketones, esters and terpenes. Despite this, studies conducted on the sensory quality of organic and conventional vegetables, have not been directly linked with volatile analysis.

The results of this study showed that the volatile emissions of Irish grown organic and conventional carrots, potatoes and tomatoes have subtle differences, but on the whole, the volatile profiles were comparatively similar.

In the case of the raw vegetables, higher concentrations of many terpenoids, aldehydes and acids were observed in the organic vegetables compared to the conventional vegetables (Table 4.4). Organic agriculture is characterised by the prohibition of the use of synthetic agro-chemicals. In the absence any synthetic chemicals, organic vegetables have to produce a variety of natural toxins in order to protect themselves from attack by pests and disease (Croteau *et al.*, 2000). It is believed a greater quantity of these volatile compounds may have been emitted to protect the vegetables from potential predation, as natural toxin production is suppressed in the presence of synthetic chemical inputs (Matteson, 2000). Although, no synthetic pesticides were applied to the conventional tomato crop, differences were apparent between organic and conventional tomatoes. It has been reported that rockwool is cleaner and less prone to disease than soil based cultivation (Gullino *et al.*, 1999). The volatiles 2-methyl-3-oxo, ethyl ester, butanoic acid and 2-carene, which were specific to the organic tomato, may have evolved via a biochemical pathway as a natural response to trying to protect the tomato from disease. While, the volatile (*E,E*), 2,4-Heptadienal was also only found in the organic tomatoes. It is believed the organic seaweed fertiliser may have been responsible compound (Sugisawa *et al.*, 1990; Kajiwara *et al.*, 1996). The use of biological pest control may have had a significant effect for the conventional tomatoes. It is thought the aroma compound may have been released by the predatory insects as a pheromone.

In addition to this, the volatile compounds, 1,4-dichlorobenzene and 1,2-dichlorobenzene were specific to the conventional potato samples (Table 4.4). It is believed these compounds may have arisen from a chemical fungicide applied to the conventional potato crop. It is important to note that pesticide residue levels authorised in conventional farming are very low, and are most often below the minimum detection limits (Kumpulainen, 2001; Magkos *et al.*, 2006). The Department of Agriculture, Fisheries and Foods (DAFF) through its Pesticide Control Service (PSC), monitor pesticide residues in vegetables in Ireland to ensure consumers are not exposed to unacceptable pesticide residue levels. When pesticides are used in good agricultural practices, unacceptable levels of pesticides should not occur in treated vegetables (Department of Agriculture Fisheries and Food, 2008).

The concentrations of some pyranones and furanones were significantly higher in the raw conventional tomatoes compared to the raw organic tomatoes (Table 4.4). This was attributed to the fact that the conventional tomatoes contained significantly higher quantities of fructose than the organic tomatoes. Fructose produced a complex set of volatile intermediary metabolites, of which 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one was a dominant compound.

In the case of the cooked vegetables, temperature had a significant effect on the volatile profiles of the organic and conventional vegetables. Most of the terpenoids previously detected in the raw vegetable samples, were lost after cooking. These losses most likely occurred due to the leaching of compounds into the cooking liquid, evaporation of compounds into the atmosphere and/or degradation of enzymes during heat treatment (Alasalvar *et al.*, 1999). Heating the tomatoes resulted in higher concentrations of pyranones and furanones detected in the organic and conventional tomatoes. This increase was attributed to the thermal degradation of sugars and the Maillard reaction.

Table 4.4: Summary table for the volatile emissions of organic and conventional vegetables, before and after cooking.

Raw Carrot [a]	**Steamed Carrot** [a]	**Baked Potato** [a,b]	**Raw Tomato** [a,b]	**Heated Tomato** [a,b]
Organic: limonene, *p*-cymene humulene	***Organic:*** terpinolene γ-terpinene	***Organic:*** 2-butanol Biphenyl	***Organic:*** **(*E*,*E*), 2,4-Heptadienal** **2-methyl-3-oxo, ethyl ester, butanoic acid** **2-carene**	***Organic:*** **2,5-pyrrolidene**
Conventional: caryophyllene terpinolene sabiene α-pinene γ-terpinene	***Conventional:*** α–patchoulene	***Conventional:*** **1,4-dichlorobenzene** **1,2-dichlorobenzene**	***Conventional:*** ***o*-chloroanisole** **pentadecanal** 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one, maltol 5-hydroxymaltol	***Conventional:*** 2-furanmenthanol, 2H-pyran-2-one 2,5-dimethyl-4 hydroxy-3(2H)-furanone 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one 5-methyl-2-furancarboxaldehyde

[a] Volatiles detected in high concentrations are indicated in normal font

[b] Volatile compounds specific to organic or conventional growing system are indicated in bold font

CHAPTER 5

5.1 GENERAL INTRODUCTION

"Every lifestyle magazine regards organic food as synonymous with healthy living and every TV chef tells us that organic food tastes better. To question claims made by the organic lobby is not just akin to doubting the virtues of motherhood, but to reveal indifference to the poisoning of the nation and the fate of the planet"

Dick Taverne (2005)

Organically farmed foods cost the Irish consumer considerably more to buy than conventionally produced food. Price premiums of between 20 and 70% have reportedly been charged for organic produce (Pope, 2009). Baltzer (2003) found that consumers believe the higher price charged for organic produce is justified based on the quality. Research studies conducted on consumer attitudes towards organically farmed foods suggest that the consumption of organic food is related to decreasing confidence in the quality of conventional foods (Saba and Messina, 2003). Public concern has been influenced by the numerous high profile food scares (B.S.E, Dioxin contamination) that have been reported by the media in the past. The preference for organic fruit and vegetables has also been associated with an increased interest towards personal health, better taste and environmental protection (Magkos *et al.*, 2006). The objectives of this study were (1) to establish if selected Irish organic vegetables (raw or cooked) have better sensory properties than selected Irish conventional vegetables (raw or cooked), and (2) to test the hypothesis that consumer preference for organically farmed vegetables is significantly higher than that of conventionally produced vegetables.

5.2 A COMPARISON OF THE SENSORY QUALITY OF ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING

5.2.1 SENSORY COLOUR SCORES OF ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING BY A TRAINED PANEL

No significant difference was observed between the organic and conventional raw carrots, and between the organic and conventional steamed carrots for intensity of colour attribute (Table 5.1 and Table 5.2). Colour is an important sensory characteristic of carrots and is affected by both environmental and chemical factors. In a study conducted by Rosenfeld *et al.* (1997) it was reported that carrots which were grown at high temperatures (15^{o}C; 18^{o}C & 21^{o}C) received higher sensory scores for colour strength and hue than those cultivated in low temperatures (9^{o}C & 12^{o}C). However, in this study variations in climatic conditions were minimal.

5.2.2 SENSORY AROMA SCORES OF ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING BY A TRAINED PANEL

A comparison between the organic and conventional raw carrots, and between the organic and conventional steamed carrots showed no significant difference for intensity of aroma (Table 5.1 and Table 5.2). Several authors found that cultivar largely influenced the variation in carrot sensory attributes (Seljåsen *et al.*, 2001; Varming *et al.*, 2004; Da Silva *et al.*, 2007). Schaller and Schnitzler (2000) also reported that by treating carrots grown in Mitscherlich pots with high amounts of nitrogen ($\geq$0.9g), the quantities of some aroma volatiles such as monoterpenes (α-pinene, camphene, α-phellandrene, limonene and α-terpinolene) were reduced. This would suggest that carrots treated with large quantities of nitrogen would have a reduced pine aroma compared to those fertilised with low amounts of nitrogen. The influence of these variables was minimised in this study.

Table 5.1 Sensory evaluation scores of organic and conventional raw carrots by a trained panel.

Parameters	Organic	Conventional
Intensity of Colour	6.6 ± 1.1^{a}	6.2 ± 1.2^{a}
Intensity of Carrot Aroma	4.0 ± 1.1^{a}	3.8 ± 1.4^{a}
Hardness	6.0 ± 0.9^{a}	5.8 ± 1.1^{a}
Crunchiness	6.3 ± 1.1^{a}	6.6 ± 0.9^{a}
Juiciness	5.5 ± 1.5^{a}	5.5 ± 1.7^{a}
Sweetness	4.5 ± 1.4^{a}	4.3 ± 1.1^{a}
Bitterness	2.0 ± 1.0^{a}	2.1 ± 1.0^{a}

Data are the mean values (± standard deviation) of organic and conventional raw carrots. Values bearing different superscripts are significantly different ($p \leq 0.05$).

Table 5.2 Sensory evaluation scores of organic and conventional steamed carrots by a trained panel.

Parameters	Organic	Conventional
Intensity of Colour	7.3 ± 1.1^{a}	7.3 ± 1.1^{a}
Intensity of Carrot Aroma	7.2 ± 1.2^{a}	7.4 ± 0.9^{a}
Hardness	2.4 ± 1.0^{a}	2.1 ± 0.9^{a}
Crunchiness	1.9 ± 0.7^{a}	2.0 ± 0.7^{a}
Juiciness	3.5 ± 1.0^{a}	3.6 ± 1.2^{a}
Sweetness	3.4 ± 1.0^{a}	3.6 ± 1.2^{a}
Bitterness	1.8 ± 0.7^{a}	1.8 ± 0.8^{a}

Data are the mean values (± standard deviation) of organic and conventional steamed carrots. Values bearing different superscripts are significantly different ($p \leq 0.05$).

5.2.3 Sensory texture scores of organic and conventional carrots before and after steaming by a trained panel

No significant differences were observed between the organic and conventional raw carrots for hardness, crunchiness and juiciness. Nor, were any differences observed between the organic and conventional steamed carrots for any of the textural attributes studied (Table 5.1 and Table 5.2). Texture plays a key part in consumer acceptance of fresh carrots. Before and during consumption, the visual, auditory and tactile textural parameters are of prime importance (Son Vu *et al*., 2006). Consumers generally prefer carrots to be hard, crunchy and juicy (Szymczak *et al.,* 2007). In this study, the trained panel perceived both the organic and conventional raw carrots to have a moderate degree of hardness, crunchiness, and juiciness, while both types of cooked carrot were perceived to be very slightly hard and crunchy, and slightly juicy. Carrot texture is affected by both climatic and agronomic factors. Rosenfeld *et al.* (2002) documented that carrots grown at high temperatures ($\geq 15^{o}$C) scored higher for firmness than those cultivated at low temperatures ($\leq 12^{o}$C). While, Hogstad *et al.* (1997) recorded higher sensory scores for juiciness in carrots that were exposed to low levels of precipitation (186-330mm) than those exposed to higher levels of precipitation (528-730mm) during the growing season. In this study, both types of carrot grew at an average temperature of 13^{o}C and were exposed to precipitation levels of ~700mm during the growing season, season and conversely no significant difference was found for textural scores by the panel. The trained panel perceived the organic and conventional carrots both to be moderately hard and moderately juicy.

5.2.4 SENSORY TASTE SCORES OF ORGANIC AND CONVENTIONAL CARROTS BEFORE AND AFTER STEAMING BY A TRAINED PANEL

Sweetness and bitterness are also two very important sensory characteristics of carrots and play a major role in determining consumer acceptability. It was reported that sweetness can increase carrot flavour acceptability, while bitter tastes may result in consumer rejection of carrot varieties (Simon *et al.*, 1980; Alasalvar *et al.*, 2001). A comparison between the organic and conventional raw carrots, and between the organic and conventional steamed carrots found no significant difference for sweetness or bitterness intensities (Table 5.1 and Table 5.2). Both the organic and conventional raw carrots were described as having a moderately sweet taste, and a just detectable bitter taste. While, the organic and conventional steamed carrots were perceived to be slightly sweet with a just detectable bitter taste.

According to Rosenfeld *et al*. (2002) carrots grown in high temperatures (15^{o}C to 21^{o}C) scored higher for bitterness and aftertaste than those cultivated in low temperatures (below 12^{o}C). While, carrots grown at lower temperatures were perceived to have a sweeter and more acidic taste than those grown in high temperatures.

5.2.5 CONSUMER SENSORY ANALYSIS SCORES OF ORGANIC AND CONVENTIONAL RAW CARROTS

A total of seventy-five consumers participated in a sensory test on organic and conventional carrots (Appendix G). The results of this test did not show any statistically significant differences for appearance, aroma, texture and taste acceptability attributes between the organic and conventional raw carrots (Table 5.3).

Table 5.3 Sensory evaluation scores of organic and conventional raw carrots by a consumer panel.

Sensory Parameters	**Organic**	**Conventional**
Appearance	7.0 ± 1.4^{a}	7.4 ± 1.1^{a}
Aroma	6.4 ± 1.5^{a}	6.5 ± 1.3^{a}
Texture	7.4 ± 1.4^{a}	7.2 ± 1.6^{a}
Taste	7.6 ± 1.0^{a}	7.4 ± 1.0^{a}

Data are the mean values (± standard deviation) of organic and conventional raw carrots by consumer panel. Values bearing different superscripts are significantly different ($p \leq 0.05$).

The consumers indicated they “liked moderately” the appearance, aroma, texture, and taste acceptability attributes of the organic and conventional raw carrots.

The results of the paired preference test also revealed there was no statistically significant difference for preference between the organic and conventional raw carrots.

5.1.6 SUMMARY OF CARROT RESULTS

No perceptible difference existed between the sensory profiles of organic and conventional carrot samples, whether raw (consumer and trained panel) or steamed (trained panel).

5.3 A COMPARISON OF THE SENSORY QUALITY OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING

5.3.1 SENSORY COLOUR SCORES OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING BY A TRAINED PANEL

Sensory scores for skin and flesh colour of the raw organic and conventional potatoes are shown in Table 5.4. No significant differences were observed between the organic and conventional raw potatoes for skin and flesh colour. The organic and conventional raw potatoes were described as having a creamy white external colour and a pale yellow internal colour. While, the baked organic and conventional potatoes were described as having a pale yellow internal colour. The results of this study are in agreement with the findings of Hajšlová *et al.* (2005) who reported no significant difference between organic and conventional steamed potatoes for surface colour and appearance of cut tubers. Wszelaki *et al.* (2005), found panellists could only distinguish between boiled organic and conventional potatoes provided the tubers were in their skins. In that study, it was believed the sensory difference perceived between potato samples was related to a combination of factors, namely the physiological age of the potato tubers, climatic conditions and glycoalkaloid levels. For this study, both the organic and conventional potatoes were grown in the same geographic location and were exposed to the same environmental and pre- and postharvest conditions. These controlled measures ensured variations between the organic and conventional potato samples were lessened in so far as possible.

Table 5.4 Sensory evaluation scores of organic and conventional raw potatoes by a trained panel.

Parameters	Organic	Conventional
External Colour	1.9 ± 1.0^{a}	2.0 ± 1.0^{a}
Internal Colour	1.5 ± 0.8^{a}	1.6 ± 0.8^{a}
Raw Potato Aroma	3.3 ± 1.5^{a}	2.9 ± 1.2^{a}
Mustiness	2.7 ± 1.3^{a}	2.8 ± 1.3^{a}
Earthiness	3.2 ± 1.4^{a}	3.6 ± 1.6^{a}
Hardness	7.7 ± 1.1^{a}	7.8 ± 1.0^{a}
Moistness	6.6 ± 1.1^{a}	6.4 ± 1.1^{a}

Data are the mean values (± standard deviation) of organic and conventional raw potatoes by a trained panel. Values bearing different superscripts are significantly different ($p \leq 0.05$).

Table 5.5 Sensory evaluation scores of organic and conventional baked potatoes by a trained panel.

Sensory Parameters	Organic	Conventional
Internal Colour	1.5 ± 0.8^{a}	1.4 ± 0.7^{a}
Cooked Potato Aroma	6.4 ± 1.5^{a}	6.3 ± 1.5^{a}
Mustiness	2.9 ± 1.4^{a}	2.9 ± 1.4^{a}
Earthiness	3.9 ± 1.3^{a}	3.6 ± 1.1^{a}
Hardness	3.5 ± 0.9^{a}	2.5 ± 0.9^{b}
Adhesiveness	5.2 ± 1.3^{a}	4.3 ± 1.4^{b}
Moistness	2.8 ± 1.4^{a}	3.9 ± 1.4^{b}
Sweetness	3.4 ± 1.0^{a}	3.5 ± 1.0^{a}
Aftertaste	3.2 ± 1.2^{a}	3.3 ± 1.2^{a}

Data are the mean values (± standard deviation) of organic and conventional baked potatoes by a trained panel. Values bearing different superscripts are significantly different ($p \leq 0.05$).

5.3.2 SENSORY AROMA SCORES OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING BY A TRAINED PANEL

Intensity of potato aroma, mustiness and earthiness are common descriptors used to describe raw and cooked potato aroma (Montouto-Graña *et al*., 2002). A comparison between the organic and conventional raw potatoes, and between the organic and conventional baked potatoes found no significant difference for aroma intensity, mustiness and earthiness (Table 5.4 and Table 5.5). The trained panel perceived both types of raw potato to have a very slight potato aroma, as well as a very slight degree of mustiness and earthiness. Whereas, the organic and conventional baked potatoes were found to have a moderately intense potato aroma, with a slight musty and earthy note. Hajšlová *et al.* (2005) also reported no significant difference between organic and conventional steamed potatoes for aroma attributes.

5.3.3 SENSORY TEXTURE SCORES OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING BY A TRAINED PANEL

A comparison between the organic and conventional raw potatoes found no significant difference for the sensory attributes of hardness and moistness (Table 5.4). The trained panel perceived both the organic and conventional potatoes to be hard, displaying a moderate level of surface moisture, once cut. However, once baked statistically significant differences ($p \leq 0.05$) were observed for the textural attributes of hardness, adhesiveness and moistness between the organic and conventional baked potato samples (Table 5.5). The trained panel found the baked conventional potatoes to be softer ($p \leq 0.05$), less adhesive ($p \leq 0.05$) and wetter ($p \leq 0.05$) than the baked organic potatoes.

5.3.4 SENSORY TASTE SCORES OF ORGANIC AND CONVENTIONAL POTATOES BEFORE AND AFTER BAKING BY A TRAINED PANEL

A comparison between the organic and conventional baked potato samples found no significant differences for the sensory attributes of sweetness and aftertaste (Table 5.4 and Table 5.5). The trained panel perceived the organic and conventional baked potatoes to be slightly sweet and have a slight lingering aftertaste. Wszelaki *et al.* (2005) also reported no significant difference between organic and conventional boiled potatoes for taste attributes.

5.3.5 Consumer sensory analysis scores of organic and conventional baked potatoes

A total of eighty consumers participated in the baked potato sensory test (Appendix G). The results of the consumer sensory evaluations of the organic and conventional baked potatoes did not show any statistically significant differences for appearance, aroma, texture and taste acceptability attributes (Table 5.6). The consumers indicated they “liked moderately” the appearance, aroma, texture and taste acceptability attributes of the organic and conventional baked potatoes. The paired preference test results also revealed there was no statistically significant difference for preference between the organic and conventional baked potatoes. Similar findings, with no significant preference for boiled and steamed potatoes from different growing systems were reported (Hajšlová *et al.*, 2005; Wszelaki *et al.*, 2005).

Table 5.6 Sensory evaluation scores of organic and conventional baked potatoes by a consumer panel.

Sensory Parameters	Organic	Conventional
Appearance	7.0 ± 1.4^{a}	7.1 ± 1.6^{a}
Aroma	7.2 ± 1.3^{a}	7.2 ± 1.4^{a}
Texture	6.8 ± 1.6^{a}	7.0 ± 1.5^{a}
Taste	7.0 ± 1.6^{a}	7.2 ± 1.6^{a}

Data are the mean values (± standard deviation) of organic and conventional baked potatoes by consumer panel. Values bearing different superscripts are significantly different ($p \leq 0.05$).

5.3.6 Summary of potato results

The organic growing conditions in this study appear to have had a significant impact on the textural attributes of the baked potatoes (*cv*. Orla), but do not seem to have affected appearance, aroma or texture attributes of the raw potatoes. Moreover, the consumer panel did not show a preference for the baked organic potatoes when compared with the baked conventional potatoes.

5.4 A COMPARISON OF THE SENSORY QUALITY OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING

5.4.1 SENSORY COLOUR SCORES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING BY A TRAINED PANEL

No significant differences were observed between the organic and conventional whole tomato samples for colour intensity (Table 5.7). Both the organic and conventional tomatoes were described as having a red ripe colour. Nor were any significant differences apparent between the heated organic and conventional tomato macerates for the intensity of colour attribute (Table 5.8). These findings are in agreement with the instrumental colour results. Colour is a particularly important sensory attribute for tomatoes, as it affects the consumer's initial perception of quality (Stommel *et al*., 2005). Both the organic and conventional tomatoes were harvested on the same day at the red ripe stage, in order to minimise variations in the physiological age of the tomatoes.

5.4.2 SENSORY AROMA SCORES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING BY A TRAINED PANEL

A comparison between the organic and conventional whole tomatoes, and between the organic and conventional heated tomato macerates found no significant difference in aroma intensity (Table 5.7 and Table 5.8). Heating did have a significant effect ($p \leq 0.05$) on the intensity of tomato aroma. The organic and conventional heated tomatoes were perceived to have a more intense aroma when compared to the raw tomatoes.

Table 5.7 Sensory evaluation scores of organic and conventional whole tomatoes by a trained panel.

Sensory Parameters	Organic	Conventional
Intensity of Colour	6.1 ± 0.8^{a}	6.1 ± 0.7^{a}
Intensity of Tomato Aroma	3.9 ± 1.2^{a}	3.7 ± 1.2^{a}
Finger Feel Firmness	3.8 ± 1.2^{a}	3.9 ± 1.2^{a}
Juiciness	5.1 ± 1.3^{a}	5.0 ± 1.3^{a}
Texture During Mastication	3.5 ± 1.1^{a}	3.8 ± 1.1^{a}
Sweetness	2.2 ± 1.1^{a}	3.9 ± 1.1^{b}
Sourness	3.9 ± 1.2^{a}	2.5 ± 1.2^{b}

Data are the mean values (± standard deviation) of organic and conventional whole tomatoes by a trained panel. Values bearing different superscripts are significantly different ($p \leq 0.05$).

Table 5.8 Sensory evaluation scores of organic and conventional cooked tomato macerates a trained panel.

Sensory Parameters	Organic	Conventional
Intensity of Colour	3.0 ± 0.8^{a}	3.2 ± 1.0^{a}
Intensity of Tomato Aroma	6.3 ± 1.0^{a}	6.4 ± 1.0^{a}
Thickness	4.6 ± 0.9^{a}	4.6 ± 1.0^{a}
Sweetness	2.2 ± 0.9^{a}	3.2 ± 0.9^{b}
Sourness	2.7 ± 0.8^{a}	2.0 ± 0.7^{b}

Data are the mean values (± standard deviation) of organic and conventional cooked tomato macerates by a trained panel. Values bearing different superscripts are significantly different ($p \leq 0.05$).

5.4.3 SENSORY TEXTURE SCORES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING BY A TRAINED PANEL

No significant differences were observed between the organic and conventional whole tomatoes for finger feel firmness, texture during mastication and juiciness (Table 5.7). In study conducted by Thybo *et al*. (2006), a trained panel found hydroponically grown tomatoes to be firmer than soil cultivated tomatoes, but instrumental textural analysis of both the soil grown and hydroponic tomato showed no difference for firmness. A comparison between the organic and conventional heated tomato macerates found no significant differences for thickness scores.

5.4.4 SENSORY TASTE SCORES OF ORGANIC AND CONVENTIONAL TOMATOES BEFORE AND AFTER HEATING BY A TRAINED PANEL

Statistically significant differences ($p \leq 0.05$) were observed for sweetness and sourness values of the organic and conventional tomatoes (Table 5.7 and Table 5.8). The trained panel found the conventional tomatoes to be significantly sweeter and less sour than their organic counterparts, whether raw or heated.

5.4.5 CONSUMER SENSORY ANALYSIS OF ORGANIC AND CONVENTIONAL TOMATOES

Seventy-two consumers participated in the organic and conventional tomato sensory test (Appendix G). The results of the triangle test indicated that there was a detectable difference ($p \leq 0.05$) between the organic and conventional tomatoes. Fifty-three percent of the consumers correctly identified the odd sample, while 47% could not discriminate between the organic and conventional tomatoes.

Table 5.9: Triangle Test Results

Tomatoes served as odd sample	Number of judgments	Number of correct judgments	Number of correct judgments necessary to establish significance (p<0.05)
	72	38*	32
Organic	36	17	
Conventional	36	21	

Based on the total number of correct judgments (out of the total of 72 judgments)
* Significant

In addition to this the results of the paired preference test showed a significant preference ($p \leq 0.05$) for the conventional tomatoes. Fifty-eight consumers (81%) favoured the conventional tomatoes compared to fourteen consumers (19%) who preferred the organic tomatoes. The main reason for choosing the conventional tomato as their preferred choice was sweet taste ($p \leq 0.05$).

5.3.6 SUMMARY OF TOMATO RESULTS

The conventional growing conditions appear to have significantly affected the taste properties of the tomatoes (*cv*. Amoroso) in this study. Both the trained and consumer panel perceived the conventional tomatoes to be notably sweeter than their organic counterparts. However, no perceptible differences were apparent between the organic and conventional tomatoes for the sensory attributes of appearance, aroma and texture.

5.5 OVERALL SUMMARY OF RESULTS OF THE SENSORY PROPERTIES OF ORGANIC AND CONVENTIONAL VEGETABLES

Currently, Irish consumers are paying significant price premiums for organically farmed vegetables based on some cases of unscientifically sound and biased media coverage. However, until now there was no information available to consumers to indicate whether or not the sensory quality of organic carrots, potatoes and tomatoes were superior to conventionally cultivated carrots, potatoes and tomatoes. The results of this study showed few differences were observed between the sensory attributes of the organic and conventional vegetables. The trained sensory panel perceived the baked conventional potatoes to be softer, less adhesive and wetter than the baked organic potatoes. While, conventional tomatoes were found to be significantly sweeter and less sour than the organic tomatoes (Table 5.10 and Table 5.11).

Overall, the sensorial quality of the organically farmed carrots, potatoes and tomatoes was not superior to the conventionally produced carrots, potatoes and tomatoes. Consumer preference for organic vegetables was not higher than that of conventional vegetables.

Table 5.10: Summary of sensory quality differences between organic and conventional vegetables as identified by the trained panel.

Sensory Attributes	**Raw Carrot** Organic v Conventional	**Cooked Carrot** Organic v Conventional	**Raw Potato** Organic v Conventional	**Cooked Potato** Organic v Conventional	**Raw Tomato** Organic v Conventional	**Cooked Tomato** Organic v Conventional
Appearance	N.S	N.S	N.S	N.S	N.S	N.S
Aroma	N.S	N.S	N.S	N.S	N.S	N.S
Texture	N.S	N.S	N.S	$p \leq 0.05$	N.S	N.S
Taste	N.S	N.S	N/A	N.S	$p \leq 0.05$	$p \leq 0.05$

N.S: Not Significant
N/A: Not Applicable

Table 5.11: Summary of sensory quality differences between organic and conventional vegetables as reported by consumer panels

Sensory Attributes	**Raw Carrot** Organic v Conventional	**Baked Potato** Organic v Conventional	**Raw Tomato** Organic v Conventional
Appearance	N.S	N.S	N/A
Aroma	N.S	N.S	N/A
Texture	N.S	N.S	N/A
Taste	N.S	N.S	N/A
Preference	N.S	N.S	$p \leq 0.05$

N.S: Not Significant
N/A: Not Applicable

CHAPTER 6

6.1 FACTORS AFFECTING THE SENSORY PROPERTIES OF ORGANIC AND CONVENTIONAL CARROTS, POTATOES AND TOMATOES

Results from comparative studies of organic and conventional vegetables are often open to misinterpretation because of the influence of many pertinent variables. These variables are discussed below.

6.1.1 GENETIC VARIETY

According to Heaton (2001) differences in genetic variation may explain differences in taste between organic and conventional vegetables. Haglund *et al*. (1999) found that genetic variation influenced the sensory attributes of organic and conventional carrots. In the afore mentioned study, the cultivar Nandor was significantly sweeter than the cultivars Narbonne and Newburg. Maggio *et al*. (2008) also indicated that potato size characteristics, dry matter content and nutrient composition are parameters that vary greatly among cultivars. While, Vogtmann *et al.* (1993) noted that two out of three organic varieties of tomatoes tasted better than their conventional counterparts. In this study, the same genetic varieties of carrots (*cv*. Nairobi), potatoes (*cv*. Orla) and tomatoes (*cv*. Amoroso) were grown organically and conventionally. The same cultivars were purposely used so that the impact of genetic variety could be eliminated as a source of difference between the organic and conventional samples.

6.1.2 CLIMATIC CONDITIONS

Theuer (2006) reported that many published comparative studies on organic and conventionally produced vegetables provide little information on the climatic conditions which the vegetable crops were exposed to. However, climatic conditions can have a profound influence on the sensory properties of vegetables (Grierson and Kader, 1986; Eskin, 1989; Rosenfeld *et al.*, 1997). Baardseth *et al.* (1995) and Hogstad *et al.* (1997), found that carrots exposed to low levels of precipitation (≤186mm) were crispier and juicier than those exposed to high levels of rainfall (≥528mm). According to Haverkort (1990) potatoes grow best in temperate climates. High temperatures can result in low yields, due to increased development rates and higher respiration (Hijmans, 2003). At very cold temperatures (0^{o}c), potato crops are vulnerable to severe frost damage (Hijmans *et al.*, 2003). Davies and Hobson (1981) also documented that tomato flavour is greatly affected by exposure to sunlight and temperature. In this study, similar mean temperatures, mean levels of precipitation and mean hours of sunshine were recorded between the crop sites. The climatic conditions did not vary between any of the three types of organic and conventional vegetables in this study and could be dismissed as a possible source of variation.

6.1.3 GEOGRAPHIC LOCATION

According to the Food Safety Authority of Ireland (2008), approximately 70% of organic food on the Irish market is imported, whereas only 30% is domestically produced. For the purpose of this study, the vegetables were all sourced in Ireland. The organic carrots were cultivated in County Offaly ($53^{o}27'$N) and the conventional carrots were grown in County

Wexford (52^{o}33´N). In the case of potatoes and tomatoes, both types of potato were grown in Co. Meath (53^{o}64´N), and the organic and conventional tomatoes were grown in County Dublin (53^{o}51´N and 53^{o}59´N). The close proximity between farms was intended to ensure that geographical and climatic effects would be similar, and could be eliminated as a cause of difference. Several authors have reported that geographical location is an important factor which can affect greatly the sensory properties of vegetables (Baardseth *et al*., 1996; Hogstad *et al*., 1997; Aherne *et al*., 2009). In a study conducted in Denmark, Varming *et al*., (2004) documented that carrots grown in northwest Zealand were perceived to be fruitier and sweeter, than those cultivated in central Jutland. While, Baardseth *et al*. (1995) found that location affected the colour of the carrots studied. The carrots cultivated at high latitudes (68^{o}46´N) in Norway were lighter in colour and less red than those grown at a lower latititude (59^{o}23´N). Potatoes grown in subtropical locations have a shorter growing time than those grown in England, Scotland, Wales and Finland (Hijmans, 2003). The significance of this is that potatoes which were harvested less than 62 days after planting had less reducing sugars than those which were harvested after 85 days. Aherne *et al*. (2009) stated that geographic location (Spain v Ireland) had a more pronounced effect on carotenoid content than tomato type. The Spanish tomatoes were found to have a higher carotenoid content than the Irish tomatoes. It may be concluded that geographic location, being a composite factor of climatic conditions and cultivation systems could provide an explanation for the variation in sensory quality of some organic and conventional vegetables. However, in this study, the impact of geographic location on the sensory quality of Irish grown organic and conventional carrots, potatoes and tomatoes was minimal.

6.1.4 COMPARATIVE STUDIES

Most comparative studies conducted to date, on organic and conventional vegetables fall into one of three categories, those being retail market, farm or cultivation studies (Magkos et al., 2006). In farm and cultivation studies the exact conditions the vegetables were grown under is known. It is believed that comparisons of organic and conventional vegetables from retail studies do not permit adequate assessment of consumer perception, given the potentially confounding cultivar and environmental effects (Zhao et al., 2007). Market-orientated studies, do however, reflect the quality of products in commercial outlets and are therefore more applicable to the consumer (Magkos et al., 2003). When conducting market orientated studies, it is important that the exact agronomic and climatic conditions the vegetables are subjected to, as well as the physiological age are known. Physiological age can have a considerable affect on the sensory properties of vegetables (Péneau et al., 2006). Since changes due to ageing vary greatly between vegetables at different stages of maturity, investigation of vegetables that specifically differ according to this characteristic is futile. In this study, contact with all vegetable growers was established and relevant information regarding growing conditions, physiological age and pre and post harvest practices was obtained.

6.1.5 IMPORTANCE OF CONTROLLING PERTINENT VARIABLES

Several reviews conducted on the sensory quality of organic and conventional vegetables highlighted many discrepancies in the literature, and stressed the need for well controlled studies to be conducted (Woese *et al.,* 1997; Heaton, 2001; Bourn and Prescott, 2002; Lester 2006; Theuer, 2006). Many of the studies reviewed were flawed by a number of confounding factors (cultivar, physiological age, soil type) that may have contributed to the differences that were reported (Basker, 1992; Bordeleau *et al*., 2002; Wszelaki *et al*., 2005). Addressing the sensory quality of organic and conventionally farmed vegetables is a complex matter, especially in the face of scarce and conflicting data. Overrating or generalising identified trends is neither scientifically defensible or a prudent public stance to take. Valid sensory quality comparisons between organic and conventional foods, require that plants be cultivated in similar soils, grown under similar climatic conditions, be sampled at the same time and be analysed using validated methods. Without all essential information regarding the growing systems, comparing organic and conventionally produced vegetables would unequivocally lead to reduced validity of the conclusions. Therefore, to ascertain whether or not sensory differences exist between organic and conventional vegetables, it is essential that the comparative studies are rigorously controlled, ensuring the effects of all pertinent variables are minimised.

6.2 THE SIGNIFICANCE OF USING A TESTING PROTOCOL INCORPORATING OBJECTIVE AND SUBJECTIVE METHODOLOGY

Using both physicochemical and sensory analysis showed that the only significant differences which occurred were in the potato and the tomato. In the case of the potato, there was a textural difference which was detected by the Instron universal texture machine and dry matter content, and by the trained panel. Whether raw or baked, the organic potato was firmer than the corresponding conventional sample. For the tomato, there were significant taste differences. Differences were detected by instrumental sugar and ^{o}Brix analysis methods, as well as the consumer and trained sensory panels. In both cases the conventional tomatoes were proven to be sweeter than the organic tomatoes. The trained sensory panel perceived the organic tomatoes to be significantly sourer than the conventional tomatoes. Further analysis of the tomato volatile emissions proved to be very significant for understanding the flavour difference between organic and conventional samples. The aroma volatiles (*E*,*E*), 2,4-Heptadienal and 2-carene were detected only in the organic tomatoes. These two volatiles are responsible for imparting green aromas. It was reported that the presence of earthy, musty, vine and green compounds can increase the perception of sourness, whereas, some fruity floral aromas are thought to enhance the perception of sweetness (Baldwin *et al.*, 1998). It is believed these volatile compounds may have enhanced the perception of sourness in the organic tomatoes. In addition to this, concentrations of the volatiles 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one, maltol and 5-hydroxymaltol were higher in the raw and heated conventional tomatoes compared to the raw and heated organic tomatoes. The significantly higher concentrations of these volatiles found in the conventional tomatoes may have further increased the perception of sweetness.

Vegetable flavour results, mainly from a complex interaction between volatile components, and sugars and acids (Petró-Turza, 1987; Bruhn *et al.*, 1991; Alasalvar *et al.*, 2001). The flavour of organic vegetables have been the topic of considerable debate (Theuer, 2006; Food Safety Authority of Ireland, 2008b). Focusing on the appearance, texture and taste properties of organic and conventional vegetables, underscores the importance of aroma, which plays a major role in flavour perception. In this study, the fact that aroma compounds found in the organic and conventional tomatoes affected the sensory perception of flavour, suggests it is vital that future comparisons of organic and conventional vegetables should incorporate volatile analysis in their study design. Using one type of testing method does not reveal the complete picture. It is necessary to use a combined approach of studying the physicochemical composition, volatile emissions and sensory properties of organic and conventional vegetables, before any meaningful conclusions can be reached.

6.3 IMPLICATIONS OF THIS RESEARCH ON CONSUMER PERCEPTION

6.3.1 TASTE

In a study conducted by Bord Bia (2008b) it was reported that 55% of organic shoppers and 13% of non organic buyers perceived organic produce to be tastier than conventional produce. This finding is also in agreement with several European studies (Tregear *et al.*, 1994; Makatouni, 2002; Radman, 2005). However, the results of this study showed very few differences were evident between the organic and conventional vegetables (raw or cooked) for taste, with the exception of tomatoes. These findings, which are based on scientifically valid experiments, are contradictory to what the media or organic advocates tell us (IFOAM, 2009).

6.3.2 SAFETY

One of the main drivers of organic vegetables is the differentiation between organic and conventional vegetables with respect to pesticide use and perceived pesticide residues. Research in the area of risk perception has indicated that the public is strongly concerned about the potential dangers of pesticides on vegetable produce (Saba and Messina, 2003).

Bord Bia (2008b) stated that 73% of organic consumers purchase organic produce as they believe that it is free from chemicals and pesticides. Such limitations in available pesticides and the restrictions on their use should result in fewer pesticide residues in organic crops relative to conventional crops (Winter and Davis, 2006). However, it is important to note that pesticide residue levels authorised in conventional farming are very low, and are most often below the minimum detection limits (Kumpulainen, 2001; Magkos *et al.*, 2006). In this study, both the organic and conventional carrot crops were treated with organic and synthetic inputs respectively, as well as being covered with insect crop covers to protect the carrots from an attack of carrot fly. According to Kruidhof *et al.*, (2008) by using a crop cover, competition between the crop cover and weed seeds for limited resources such as light water and available nutrients is created. Similarly, organic and synthetic inputs were applied to organic and conventional potato crops to prevent an outbreak of blight. The volatile compounds, 1,4-dichlorobenzene and 1,2-dichlorobenzene were isolated in the baked conventional potato samples. It is believed these compounds may have arisen from a chemical fungicide applied to the conventional potato crop. The Department of Agriculture, Fisheries and Foods (DAFF) through its Pesticide Control Service (PSC), monitor pesticide residues in vegetables in Ireland to ensure consumers are not exposed to unacceptable pesticide residue levels. When pesticides are used in good agricultural practices, unacceptable levels of pesticides should not occur in treated vegetables (Department of Agriculture Fisheries and Food, 2008). Both the organic and conventional growing systems for the tomatoes, incorporated biological pest control in their greenhouse. Pests were controlled naturally using parasitic wasps (*Encarsia formosa*) and predatory insects (*Macrolophus caliginosus*). No synthetic chemical inputs were applied to either crop.

6.3.3 PRICE

Price is another important factor for determining acceptability and merchantability of organic produce. Generally organically farmed foods sell for higher prices than conventionally produced foods and this may be explained by higher productions costs and lower yields associated with organic agriculture (Maggio *et al.,* 2008). Several authors have indicated that price was a significant deterrent for consumers to buy organic food (Tregear *et al.,* 1994; Magnusson *et al.,* 2001; Padel and Foster, 2005; Roitner-Schobesberger *et al.*, 2008). Despite this, sales of organic produce in Ireland have increased significantly (Bord Bia, 2009a). Chang and Zepeda (2004) consumers believe that the higher prices charged for organic foods are justified based on the perception about quality. These sentiments were echoed by Baltzer (2003). However, it must be noted that the acceptability of price premiums are largely dependent upon the consumer’s financial situation (Duffort, 2006). The results of this study have shown that organically farmed vegetables were not superior in sensory quality to Irish grown conventional vegetables. These findings may be of particular interest to consumers who choose to pay higher prices for organic carrots, potatoes and tomatoes over their conventional counterparts.

6.4 INFLUENCE OF THE MEDIA, GOVERNMENT AND CHEFS ON FLAVOUR PERCEPTION

6.4.1 MEDIA

Food safety is rarely out of the media spotlight and research on consumer attitudes to organic foods has indicated that the consumption of organic foods is related to decreasing confidence in the quality of conventional foods and an increasing concern for health (Saba and Messina, 2003). High profile issues like B.S.E and the dioxin contamination of pork products has undermined consumer confidence in the food industry. Moreover, growing environmental awareness has led people to question modern agricultural practices (Chen, 2007). This has been reflected in an increasing demand for organic produce, which is perceived as less damaging to the environment, healthier and tastier than conventionally grown foods. Evidence to support or refute such widespread perception is scarce (Bourn and Prescott, 2002; Magkos *et al.* 2006; Theuer, 2006).

The media have played an extremely important role in popularising organic food. Organics has become a global issue that sells television and radio air time, newspapers and magazines. The consumer is constantly petitioned by organic advocates, the organic food sector and the government via the media.

News reports about organic and conventional produce often seem both sensationalised and polarised. The relationship that has developed between the food industry, the media and consumer is one of mistrust. Food related stories will always interest consumers, but the media has a duty to restrain itself from sensationalist reporting where the facts and context are abandoned in quest for an eye catching headline (Andersen, 2000).

A better relationship between the media and the food industry would benefit consumers who rely on the two parties to supply information that influences purchase decisions. In addition to this, food scientists and food researchers must work with the media and endeavour to convey their message in a non-scientific language that will be clearly understood by the consumer.

6.4.2 GOVERNMENT

The European Action Plan for Organic Food and Farming are supporting farmers converting to organic production in an effort to try to promote and increase the amount of organic food being produced and marketed for economic, environmental and social reasons (FiBL, 2010). The Department of Agriculture, Fisheries and Food's response was to devise an organic farming action plan with a primary objective of converting a minimum 5% acreage to organic farmland by 2012, such that the organic sector receives substantial financial support from the government through the Organic Farming Scheme. Extensive marketing has also been conducted on behalf of the Irish government. Bord Bia have run a summer campaign promoting organic produce, organised a national organic week, which is now an annual event, and published many guides on organic produce (Department of Agriculture, Fisheries and Food, 2010). Having said that, the organic sector still occupies only a fraction of the market, and questions have been raised about the long term financial benefits of organic farming and whether or not organic products will ever occupy more than a niche market. Based on the projected population and demand for cheap food, the food to production process is unlikely to become less intensive in the future. Conventional vegetable production systems provide vegetables at a reasonable price and quality.

Dr. Con O'Rourke a plant scientist, believes this notion of an organic island of Ireland is an unrealistic image and would only work if we had completely self contained agriculture (Food Safety Authority of Ireland, 2008b). He stated without imported fertilisers, yields would decline to serious levels, which would impact on revenue from exports and create many job losses. Organic produce is imported around the world leading to a year round supply of certain fruits and vegetables that would have only been available during a short season (Food Safety Authority of Ireland, 2008a). The trust of the consumer in the conventional food sector is diminishing and is a key factor in risk perception. Organic advocates and the media have been able to exploit the distrust that exists between the food industry and consumer. Therefore, it is important that the government and the food industry work together to ensure consumers are assured that in terms of sensory quality conventionally produced vegetables are as good as organic.

6.4.3 CHEFS

According to Inwood *et al.* (2009) chefs have been acknowledged as potentially important partners in the campaign to promote organic food. This is certainly the case in Ireland with many prominent chefs championing organic food.

Darina Allen, Ireland's best known chef and pioneer of the slow food movement urges the Irish public to support the organic food, advocating it is not merely a luxury but a necessity. Ross Lewis of Chapter One Restaurant claims to only use organic vegetables in his restaurant (Food and Wine, 2004). While, Derry Clarke of L'Ecrivain is known to promote the use of organic food on the television (RTE, 2009). Another, key figure on the Irish culinary scene is Richard Corrigan who reportedly said " as a professional who has been cooking for 33 years, I can tell anyone who thinks organic food tastes worse than the stuff you get on a supermarket shelf needs to put his head in my deep fat fryer"(Monaghan, 2009). It might come as some surprise to him that the majority of organic food that is purchased in Ireland is taken from the supermarket shelf (Bord Bia, 2008b). Catherine Fulivo of Ballyknocken guesthouse and cookery school, also echoes Corrigan's sentiments and believes the flavours of organically farmed foods to be superior to conventional produce, despite evidence to the contrary (Monaghan, 2010).

While, it is claimed by these culinary experts that organic food tastes better, research to date has failed to show any consistent differences. With little or no advantage in sensory quality of Irish grown organic carrots, potatoes or tomatoes over their conventional counterparts, it is imperative that Irish chefs adopt a neutral stance regarding the taste of these organic vegetables.

6.5 IMPLICATIONS OF THE STUDY FOR THE MARKETPLACE

In response to the lack of scientific evidence to say whether or not a significant difference truly exists between the sensory properties of organic and conventional vegetables, a definitive testing protocol has been developed and tested. This novel testing protocol encompasses an analysis of physicochemical components, volatile emissions and sensory properties, where growing conditions have been minimised. Future studies conducted on organic and conventional foods using this protocol will provide factual and reliable information to consumers, growers, educators and policymakers alike.

6.6 KEY OUTCOMES

- The growing systems for the three model Irish vegetables investigated had little effect on the physicochemical properties of organic and conventional vegetables, whether raw or cooked.
    - Irish grown organic potatoes had a higher dry matter content than their conventionally produced counterparts. Whereas, the conventionally produced tomatoes contained more reducing sugars than organically farmed tomatoes.

- The volatile emissions of the Irish grown organic and conventional vegetables showed subtle differences, but on the whole, the volatile profiles were comparatively similar.
    - Volatile concentrations of caryophyllene, terpinolene, sabiene, α-pinene and γ-terpinene were all found in higher concentrations in the raw conventional carrots. Whereas, limonene, *p*-cymene and humulene were detected in greater quantities in the raw organic carrots.

    - The organic baked potatoes contained significantly higher concentrations of 2-butanol and biphenyl. While, 1,4-dichlorobenzene and 1,2-dichlorobenzene were only found in the conventional baked potatoes.
    - Concentrations of the volatiles 2,3-dihydro-3,5,dihydroxy-6-methyl-4H-pyran-4-one, maltol and 5-hydroxymaltol were higher for both raw and cooked conventional tomato samples compared to both types of organic samples.
    - The aroma compounds (*E,E*), 2,4-Heptadienal, 2-methyl-3-oxo, ethyl ester, butanoic acid and 2-carene were specific to the raw organic tomatoes.

- The growing systems for the three Irish vegetables investigated also had little effect on the sensory properties of organic and conventional vegetables, whether raw or cooked.
    - Very few differences were observed by the trained sensory panel between the appearance, aroma, texture and taste attributes of the organic and conventional vegetables, before and after cooking. However, the trained sensory panel perceived the baked conventional potatoes to be softer, less adhesive and wetter than the baked organic potatoes. While, conventional tomatoes were found to be significantly sweeter and less sour than the organic tomatoes.
    - Consumer sensory analysis found no differences between the organic and conventional baked potatoes, and the organic and conventional raw carrots for appearance, aroma, texture and taste acceptability attributes.

- The flavour of the organic and conventional carrots, and the organic and conventional baked potatoes were very similar. However, the conventional tomatoes were considered to be more flavoursome than the organic tomatoes.

- Until now, there was no validated information available to say whether or not, Irish grown organic vegetables were superior in sensory quality to Irish grown conventional vegetables. Proponents of organic food need to emphasise factors other than sensory quality in their decisions to recommend organically farmed vegetables over conventionally produced vegetables.

REFERENCES

Abdelgaleil, A., Mohamed, M., Badawy, M. And El-Arami, S. (2009). Fumigant and contact toxicities of monoterpenes to Sitophilus zeamais (L.) and Tribolium castaneum (Herbst) and their inhibitory effects on acetylcholinesterase activity. *Journal of Chemical Ecology*, *35*, 518-528.

Abu-Ghannam, N. and Crowley, H. (2006). The effect of low temperature blanching on the texture of whole processed new potatoes. *Journal of Food Engineering*, *74*, 335-344.

Adams, P. and Ho, L.C. (1992). The susceptibility of modern tomato cultivars to blossom end rot in relation to salinity. *Journal of Horticultural Science*, *67*, 827-839.

Adams, M.R., Hartley, A.D. and Cox, L.J. (1989). Factors affecting the efficacy of washing procedures used in the production of prepared salads. *Food Microbiology*, *6*, 69-77.

Aherne, S., Jiwan, M.A., Daly, T. and O'Brien, N.M. (2009). Geographic location has greater impact on carotenoid content and bioaccessibility from tomato than variety. *Plant Food for Human Nutrition*, *64* (4), 250-256.

Alasalvar, C., Grigor, J.M. and Quantick, P.C. (1999). Method for static headspace analysis of carrot volatiles. *Food Chemistry*, *65*, 391-397.

Alasalvar, C., Grigor, J.M., Zhang, D., Quantick, P.C. and Shahidi, F. (2001). Comparison of volatiles, phenolics, sugars, antioxidant vitamins and sensory quality of different coloured carrot varieties. *Journal of Agricultural and Food Chemistry*, *49*, 1410-1416.

Alexander, R.M. (1998). News of chews: The optimization of mastication. *Nature*, *391*, 329.

Allen, M.S. and Lacey, M.J. (1997). Stable isotope dilution gas chromatography mass spectrometry for determinations of methoxypyrazines (green aromas) in wine. In: *Plant volatile analysis* (edited by H.F. Linskens and J.F. Jackson). Pp. 193-210. New York: Springer.

Ames, J.M., Bailey, R.G. and Mann, J. (1999). Analysis of furanone, pyranone and new heterocyclic coloured compounds from sugar glycine model Maillard systems. *Journal of Agricultural and Food Chemistry*, *47* (2), 438-443.

Andersen, W.A. (2000). The future relationship between the media, the food industry and the consumer. *British Medicial Bulletin*, *56* (1), 254-268.

Angood, K.M., Wood, J.D., Nute, G.R., Whittington, F.M., Hughes, S.I. and Sheard, P.R. (2008). A comparison of organic and conventionally produced lamb purchased from three major UK supermarkets: price, eating quality and fatty acid composition. *Meat Science*, *78*, 176-184.

AOAC. (1990). *Official Methods of Analysis of AOAC International* (15th ed). Washington, DC: AOAC International.

Arias, R., Lee, T.C., Specca, D. and Janes, H. (2000). Quality comparison of hydroponic tomatoes (*Lycoperison esculentum*) ripened on and off vine. *Journal of Food Science, 65*(3), 545-548.

Arruda, D.C., Miguel, D.C., Yokoyama-Yasunaka, J.K.U., Katzin, A.M. and Uliana, S.R.B. (2009). Inhibitory activity of limonene against leishmania parasites in vitro and in vivo. *Biomedicine and Pharmacotheraphy, 63* (9), 643-649.

Atherton, J.G. and Rudich, J. (1986). *The Tomato Crop*. London: Chapman and Hall.

Auvray, M. and Spence, C. (2008). The multisensory perception of flavour. *Conciousness and Cognition, 17*, 1016-1031.

Axel, R. (1995). The molecular logic of smell. *Scientific American, 273*, 154-159.

Azodanlou, R., Darbellay, C., Luisier, J.L., Villettaz, J.C. and Amadò, R. (2003). Development of a model for quality assessment of tomatoes and apricots. *Lebensmittel Wissenschaft un Technologie- Food Science and Technology, 36* (2), 223-233.

Baardseth, H.J., Rosenfeld. T.W., Sundt, G., Skrede, P.L., Lea, P. and Slinde E. (1996). Evaluation of carrot varieties for the production of deep-fried carrot-II. Sensory Aspects. *Food Research International*, *28* (6), 513-519.

Baardseth, H.J., Rosenfeld. T.W., Sundt, G., Skrede, P.L., Lea, P. and Slinde E. (1995). Evaluation of carrot varieties for the production of deep-fried carrot-I. Chemical Aspects. *Food Research International*, *28* (3), 195-200.

Baldwin, E.A., Goodner, K., Plotto, A., Pritchett, K. and Einstein, M. (2004). Effect of volatiles and their concentration on perception of tomato descriptors. *Journal of Food Science, 69* (8), S310-318.

Baldwin, E.A., Nisperos-Carriedo, M., Shaw, P.E. and Burns, J.K. (1995). Effect of coatings and prolonged storage conditions on fresh orange volatiles, degrees Brix, and ascorbic acid levels. *Journal of Agricultural and Food Chemistry, 43* (5), 1321-1331.

Baldwin, E.A., Scott, J.W., Einstein, M.A., Malundo, T.M.M., Carr, B.T., Shewfelt, R.L. and Tandon, K.S. (1998). Relationship between sensory and instrumental analysis for tomato flavor. *Journal of the American Society of Horticultural Science, 123,* 906-915.

Baldwin, E.A. and Thompson, K. (2000). Effect of sugar type and concentration on the perception of tomato sweetness. *Proceedings of Florida State Horticultural Society, 113,* 287-289.

Baltzer, K. (2003). Estimating willingness to pay for food quality and safety from actual consumer behaviour. *83rd EAEE Seminar*, Chania, Greece, 4-6 September, 2003.

Barrett, D.M., Weakley, C., Diaz, J.V. and Watnik, M. (2007). Qualitative and nutritional differences in processing tomatoes grown under commercial organic and conventional production systems. *Journal of Food Science, 72* (9), C441-C451.

Basker, D. (1992). Comparison of taste quality between organically and conventionally grown fruits and vegetables. *American Journal of Alternative Agriculture, 7*, 129-136.

Bassil, D., Makris, D.P. and Kefalas, P. (2005). Oxidation of caffeic acid in the presence of L-cysteine: isolation of 2-*S*-cysteinylcaffeic and evaluation of its antioxidant properties. *Food Research International, 38*, 395-402.

Batu, A. (2004). Determination of acceptable firmness and colour values of tomatoes. *Journal of Food Engineering, 61* (3), 471-475.

Beaulieu, J.C. and Baldwin, E.A. (2001). Flavour and aroma of fresh cut vegetables. In: *Fresh cut fruit and vegetables: Science technology and market* (edited by O. Lamikanra). Pp. 391-425. Boca Raton: CRC Press.

Beidler, L.M. (1995). Saliva. Its function and disorders. In: *Handbook of Olfaction and Gustation* (edited by Doty, R.L). Pp. 503-519. New York: Marcel Dekker.

Beidler, L.M. (1982). Biological basis of food selection. In: *The psychobiology of human food selection* (edited by Barker, L.M). Pp. 3-15. Chichester: Ellis Horwood.

Blake, A.A. (2004). Flavour perception and learning food preferences. In: *Flavour Perception* (edited by A.J. Taylor and D.D Roberts). Pp.172-202. Oxford: Blackwell Publishing.

Bord Bia. (2009a). *Organic sales in Ireland reach €124 million* Dublin: Bord Bia. Available at: http://www.bordbia.ie/eventsnews/press/pages/50WaystoCelebrateNationalOrganicWeek,BordBia.aspx (Accessed September 22, 2009).

Bord Bia. (2009b). *Market for Horticultural products* Dublin: Bord Bia. Available at: http://www.bordbia.ie/industryinfo/hort/pages/marketforhorticulturalproducts.aspx (Accessed September 25, 2009).

Bord Bia. (2009c). *Factsheet on the Irish Agriculture and Food and Drink Sector.* Dublin: Bord Bia. Available at: http://www.bordbia.ie/industryinfo/agri/pages/default. aspx (Accessed September 25, 2009).

Bord Bia. (2009d*). Production of horticultural products*. Dublin: Bord Bia. Available at: http://www.bordbia.ie/industryinfo/hort/pages/productionofhorticulturalcrops.aspx (Accessed September 25, 2009).

Bord Bia. (2009e). *Carrots.* Dublin: Bord Bia. http://www.bordbia.ie/aboutfood/veg/carrots/pages/default.aspx (Accessed, September 25, 2009).

Bord Bia. (2009f). *Potatoes*. Dublin: Bord Bia. Available at: http://www.bordbia.ie/ about food/veg/ potatoes/pages/default.aspx (Accessed, September, 25, 2009).

Bord Bia. (2009g). *Tomatoes*. Dublin: Bord Bia.Available at: http://www.bordbia.ie/ about food /veg/ tomatoes/pages/default.aspx (Accessed, September, 25 2009).

Bord Bia. (2008a). *Organic sales in Ireland exceed €100 million* Dublin: Bord Bia. Available at: http://www.bordbia.ie/eventsnews/press/2008/Pages/OrganicsalesinIrelandexceed100million.aspx (Accessed October 6, 2008).

Bord Bia. (2008b). *Ethics, Emotions and Organic Food*. Dublin: Bord Bia. Available at: http://www.bordbia.ie/aboutus/publications/Documents/Organic%20Consumer%20Research%202008%20-%20Ethics,%20Emotions%20and%20Organic%20Food.pdf (Accessed November 22, 2008).

Bord Bia. (2007). *Bord Bia launches National Organic Week 2007*. Dublin: Bord Bia. Available at: http://www.bordbia.ie/eventsnews/press/2007/Pages/BordBialaunchesNational OrganicWeek2007.aspx (Accessed November 22, 2008).

Bord Bia. (2005). *Field vegetables census 2005*. Dublin: Bord Bia Available at: http://www.bordbia.ie/industryinfo/publications/bbreports/Documents/National%20Field%20Vegetable%20Census%202005.pdf (Accessed November 3, 2007)

Bord Bia. (2004). *National Soft Fruit and Protected Census 2004*. Dublin: Bord Bia.

Bord Bia. (2003). *Organic Food Market Developments- An Irish Perspective*. Dublin: Bord Bia.

Bord Glas. (1999). *Tomato Colour Chart*. Dublin: An Bord Glas.

Bord Glas (1995). *Fresh Produce Guide*. Dublin: An Bord Glas.

Bordeleau, G., Myers-Smith, I., Midak, M. and Szeremeta, A. (2002). Food quality: A comparison of organic and conventional fruits and vegetables. *Ecological Agriculture,* 79.

Boukobza, F. and Taylor, A.J. (2002). Effect of postharvest on flavor volatiles of tomatoes. *Postharvest Biology and Technology, 25,* 321-331.

Bourn, D.M. (1994). The nutritional value of organically and conventionally grown food-is there a difference? *Proceedings of the Nutrition Society New Zealand*, *19*, 51-57.

Bourn, D. and Prescott, J. (2002). A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. *Critical Reviews in Food Science and Nutrition, 42* (1), 1-34.

Brandt, S., Pék, Z., Barna, E., Lugasi, A. and Helyes, L. (2006). Lycopene content and colour of ripening tomatoes as affected by environmental conditions. *Journal of the Science of Food and Agriculture, 86*, 568-572.

Breslin, P.A.S. (2001). Human gustation and flavour. *Flavour and Fragrance Journal, 16*, 439-456.

Brown, C.R. (2005). Antioxidants in potato. *American Journal of Potato Research, 82*, 163-172.

Bruhn, C.M., Feldman, N., Garlitz, C., Harwood, J., Ivans, E., Marshall, M., Riley, A. and Williamson, D.T.E. (1991).Consumer perceptions of quality: apricots, cantaloupes, peaches, pears, strawberries and tomatoes. *Journal of Food Quality*, *14* (3), 187-195.

Bult, J.H.F., De Wijk, R.A. and Hummel, T. (2007). Investigations on multimodal sensory integration: Texture, taste and ortho-and retronasal olfactory stimuli in concert. *Neuroscience Letters, 411*, 6-10.

Burdock, G.A (2002) *Handbook of Flavour Ingredients*. (4th ed.). London: CRC Press

Buret, M., Gormley, R. and Roucoux, P. (1983). Analysis of tomato fruit: effect of frozen storage on compositional values –an inter-laboratory study. *Journal of the Science of Food and Agriculture*, *34*, 755-760.

Burke, J. (2003). *Growing the potato crop*. Carlow: Teagasc Available at: http://www.teagasc.ie/publications/2003/conferences/potato/paper02.asp (Accessed September 30, 2008).

Burton, W.G. (1989). *The Potato* (3rd ed). New York: Longman Scientific and Technical.

Busch, J.M., Savage, G.P. and Searle, B.P. (2008). Sensory evaluation and physicochemical measurements of tomatoes commonly consumed in New Zealand. *International Journal of Consumer Studies*, *32*, 535-544.

Buttery, R.G. (1981). Vegetable and fruit flavours In: *Flavour research* (edited by R. Teranishi, R.A. Flath and H. Sugisawa). Pp. 175-216. New York: Marcel Dekker.

Buttery, R.G. and Ling, L.C. (1993). Volatile components of tomato fruit and plant parts. In: *Bioactive volatile compounds from plants* (edited by R.Teranishi, R.G. Buttery and H. Sugisawa). Pp. 23-34. Washington D.C.: American Chemical Society.

Buttery, R.G., Ling, L.C. and Light, D.M. (1987). Tomato leaf volatile components. *Journal of Agricultural and Food Chemistry, 35*, 1039-1042.

Buttery, R.G. and Takeoka, G.R. (2004). Some unusual minor volatile components of tomatoes. *Journal of Agricultural and Food Chemistry, 52*, 6264-6266.

Buttery, R.G., Takeoka, G.R. and Ling, L.C. (1995). Furaneol: odour threshold and importance to tomato aroma. *Journal of Agricultural and Food Chemistry, 43*, 1638-1640.

Cain, W.S. (1974). Contribution of the trigeminal nerve to perceived odour magnitude. *Annals of the New York Academy of Sciences, 237*, 28-34.

Caporale, G. and Montelone, E. (2004). Influence of information about manufacturing process on beer acceptability. *Food Quality and Preference, 15* (3), 271-278.

Central Statistics Office (2009). *Area, Yield and Production of Selected Crops.* Cork: Central Statistics Office. Available at: http://www.cso.ie/quicktables/GetQuickTables.aspx?FileName=AQA03.asp&TableName=Area+Yield+and+Production+of+Selected+Crops&StatisticalProduct=DBAA (Accessed July 1, 2009).

Chang, H.S. and Zepeda, L. (2004). Consumer perceptions and demand for organic food in Austrailia: focus group discussion. *Renewable Agriculture and Food Systems, 20* (3), 155-167.

Chen, B.H., Peng, H.Y. and Chen, H.E. (1995). Changes of carotenoids, colour and vitamin A contents during processing of carrot juice. *Journal of Agricultural and Food Chemistry, 43*, 1912-1918.

Chen, J. (2009). Food oral processing- A review. *Food Hydrocolloids, 23*, 1-25.

Chen, M.F. (2007). Consumer attitudes and purchase intentions in relation to organic foods in Taiwan: Moderating effects of food related personality traits. *Food Quality and Preference, 18*, 1008-1021.

Christensen, C.M. (1980a). Effects of solution viscosity on perceived saltiness and sweetness. *Perception and Psychophysics, 28*, 347-353.

Christensen, C.M. (1980b). Effects of taste quality and intensity on oral perception and viscosity. *Perception and Psychophysics, 28*, 315-320.

Christensen, L.P., Edelenbos, M. and Kreutzmann, S. (2007). Fruits and vegetables of moderate climate. In: *Flavours and fragrances, chemistry, bioprocessing and sustainability* (edited by R.G. Berger) Pp. 135-188. New York: Springer.

Claussen, W., Bruckner, B., Krumbien A. and Lenz, F. (2006). Long term response of tomato plants to changing nutrient concentration in the root environment-the role of proline as an indicator of sensory fruit quality. *Plant Science, 171*, 323-331.

Cliffe-Byrnes, V. and O’Beirne, D. (2007). The effects of modified atmospheres, edible coating and storage temperatures on the sensory quality of carrot discs. *International Journal of Food Science and Technology*, *42*, 1338-1349.

Cliffe-Byrnes, V., Brennan, L. and O’Beirne, D. (2007). The effects of preparatory procedures and storage temperatures on the quality of carrot discs in modified atmospheres. *International. Journal of Food Science and Technology*, *42*, 482-494.

Codex Alimentarius Commission. (2001). *Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Food.* Rome: Joint Food and Agriculture Organisation/World Health Organisation.

Coleman, E.C., Ho, C-T. and Chang, S.S. (1981). Isolation and identification of volatile compounds from baked potatoes. *Journal of Agricultural and Food Chemistry, 29,* 42-48.

Commission Regulation (EC) No. 889/2008 of 5 April 2008 laying down detailed rules for the implementation of Council Regulation (EC)No 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control.

Cook, D.J., Hollowood, T.A., Linforth, R.S.T. and Taylor, A.J. (2005). Correlating instrumental measurements of texture and flavour release with human perception. *International Journal of Food Science and Nutrition, 40*, 631-641.

Council Regulation (EC) No. 834/2007 of 28 June 2007 on organic production and labeling of organic products and repealing Regulation (EEC) No. 2092/91.

Cowan, C., Connolly, L., Howlett, B., Meehan, H., Ryan, J., Mahon, D., McIntyre, B. and Fanning, M. (2005*). Final Report- The market potential for in-conversion organic products in Ireland*. Dublin: Teagasc

Croteau, R., Kutchan, T.M., Lewis, N.G. (2000). Natural Products: Secondary Metabolites. In: *Biochemistry and Molecular Biology of Plants* (edited by Buchanan, B., Gruissen, W. and Jones, R.). Pp. 1250-1318. MA: American Society of Plant Biologists.

Dangour, A.D., Dodhia, S.K., Hayter, A., Allen, E, Lock, K. and Uauy, R. (2009). Nutritional quality of organic foods: a systematic review. *American Journal of Clinical Nutrition, 90,* 680-685.

Da Silva, E.A., Viera, M.A., Viera, E.A., Amboni, R.DM.C., Amante, E.R. and Teixeira, E. (2007). Chemical, physical and sensory parameters of different carrot varieties (*Daucus carota* L.). *Journal of Food Process Engineering, 30*, 746-756.

Datta, K.K. and de Jong, C. (2002). Adverse effect of water logging and soil salinity on crop and land productivity in northwest region of Haryana, India. *Agricultural Water Management, 57* (3), 223-238.

Davidson, J.M., Linforth, R.S.T., Hollowood, T.A. and Taylor, A.J. (1999). Effect of sucrose on the perceived flavor intensity of chewing gum. *Journal of Agriculture and Food Chemistry*, 47, 4336-4340.

Davies, J.N. and Hobson, G.E. (1981). The constituents of tomato fruit, the influence of environment, nutrition and genotype. *Critical Reviews in Food Science and Nutrition*, *15,* 205-208.

Davies, J.N. and Kempton, R.J. (1975). Changes in individual sugars of tomato during ripening. *Journal of the Science of Food and Agriculture*, *26*, 1105-1110.

De Belie, N., Laustsen, A.M., Martens, M., Bro, R. and De Baerdemaeker, J. (2002). Use of physicochemical methods for assessment of sensory changes in carrot texture and sweetness during cooking. *Journal of Texture Studies, 33* (5), 367-388.

Delwiche, J. (2004). The impact of perceptual interactions on perceived flavor. *Food Quality and Preference*, *15*, 137-146.

Department of Agriculture Fisheries and Food (2010). *Organic Farming*. Available at: http://www.agriculture.gov.ie/farmingsectors/organicfarming/ (Accessed July 10, 2010).

Department of Agriculture Fisheries and Food (2009). *Annual Report 2008*. Available at: http://agriculture.gov.ie/media/migration/publications/2009/Annual%20Report%20 2008%20English.pdf (Accessed November 20, 2009).

Department of Agriculture Fisheries and Food (2008). *Pesticide residues in food, 2006*. Available at: http://www.pcs.agriculture.gov.ie/Docs/PesticidesReport2006.pdf (Accessed November 20, 2009).

Department of Agriculture Fisheries and Food (2003) *Census of Irish organic production 2002.* Department of Agriculture and Food, Wexford. Available at: http://www.agriculture.gov.ie/media/migration/farmingsectors/organicfarming/publiccations/OrganicCensus-Launched9Oct03.pdf (Accessed March 22, 2006).

Dlouhy, J. (1977). The quality of plant products under conventional and bio-dynamic management. *Bio-Dynamics, 124*, 28-32.

DuBose, C., Cardello, A. and Maller, O. (1980). Effects on colorants and flavorants on identification, perceived flavour intensity and hedonic quality of fruit flavoured beverages and cake. *Journal of Food Science*, *45*, 1393-1415.

Duffort, M.M. (2006). Minimising the impact? The meaning of organic food. Available food. Available from: http://www.atmq77.dsl.pipex.com/ (Accessed July 10, 2010).

Duizer, L. (2001). A review of acoustic research for studying the sensory perception of crisp, crunchy and crackly textures. *Trends in Food Science and Technology, 12* (1), 17-24.

Edwards, C.G. and Lee, C.Y. (1986). Measurement of provitamin A carotenoids in fresh and canned carrots and green peas, *Journal of Food Science, 51* (2), 534-535.

ElShafei, G.M.S., El-Said, M.M., Attia, H.A.E. and Mohammed, T.G.M. (2010). Environmentally friendly pesticides: Essential oil based w/o/w multiple emulsions for anti-fungal formulations. *Industrial Crops and Products, 31*, 99-106.

Eskin, N.A.M. (1989). *Quality and preservation of vegetables*. Pp. 75-121. Boca Raton: CRC Press.

Faller, A.L.K. and Fialho, E. (2009). The antioxidant capacity and polyphenol content of organic and conventional retail vegetables after domestic cooking. *Food Research International*, *42*, 210-215.

FAOSTAT. (2008). *Potato World: World Potato Production*. Available at: http://www.potato2008.org/en/world/index.html (Accessed October 29, 2008).

FAOSTAT. (2004). *Statistical Database-Agriculture*. Available at: http://faostat.fao.org/faostat/collections?subset=agriculture. (Accessed January 24, 2008).

FiBL. (2010). *European Action Plan for Organic Food and Farming*. Available at: http://www.organic-europe.net/europe_eu/action-plan-eu.asp#200409 (Accessed July 10, 2010).

FiBL/IFOAM (2009). *Organic agricultural land and producers by region 2007*. Available at: http://www.organic-world.net/statistics.html (Accessed October 10, 2008).

Fisher, C. and Scott, T.R. (1997). *Food Flavours: Biology and Chemistry*. Cambridge: Royal Society of Chemistry.

Fjelkner-Modig, S., Bengtsson, H., Stegmark, R. and Nystrom, S. (2000). The influence of organic and integrated production on nutritional, sensory and agricultural aspects of vegetable raw materials for food production. *Acta Agriculturae Scandinavia*, *Section B-Plant Soil Science*, *50*, 102-113.

Food and Wine (2004). *Ross Lewis*. Available at: http://www.foodandwine.net/chefs/chef001.htm (Accessed July 10, 2010).

Food Safety Authority of Ireland (2008a) *Organic Food*. Dublin: Food Safety Authority of Ireland.

Food Safety Authority of Ireland (2008b) Fact or Fiction. Available at: http://www.fsai.ie/details.aspx?id=3348 (Accessed July 12, 2010).

Francis, F.J. (1995). Quality as influenced by colour. *Food Quality and Preference, 6,* 149-155.

Frank, R.A., Ducheny, K. and Mize, S.J. (1989). Strawberry odor but not red color, enhances the sweetness of sucrose solutions. *Chemical Senses, 16,* 523.

Fraser, P.D., Truesdale, M.R., Bird, C.R., Schuch, W. and Bramley, P.M. (1994). Carotenoid biosynthesis during tomato fruit development. *Plant Physiology, 105,* 405-413.

Freeman, G.G. and Mossadeghi, N. (1971). Influence of sulfate nutrition on flavour components of garlic (*Allium sativum*) and wild onion (*Allium vineale). Journal of the Science of Food and Agriculture, 22,* 330-334.

Galindo, F.G., Herppich, W., Gekas, V. and Sjoholm, I. (2004). Factors affecting quality and postharvest properties of vegetables: Integration of a water relations and metabolism. *Critical Reviews in Food Science and Nutrition, 44* (3), 139-154.

Galliard, T., Matthew, J.A., Wright, A.J. and Fishwick, M.J. (1977). The enzymatic breakdown of lipids to volatile and non volatile carbonyl fragments in disrupted tomato fruits. *Journal of the Science of Food and Agriculture, 28,* 863-868.

Garcia, E. and Barrett, D.M. (2005). Evaluation of processing tomatoes from two consecutive growing seasons: quality attributes, peelability and yield. *Journal of Food Processing and Preservation*, *30*, 20-36.

Gopal, J. and Khurana, S.M.P. (2006). *Handbook of potato production, improvement, and postharvest management*. New York: Haworth Press.

Gormley, T.R. and Egan, S. (1984). Composition, colour and firmness of commercially grown tomato fruit, 1981-1983. *Irish Journal Food of Science and Technology*, *8*, 89-98.

Gormley, T.R. and Egan, S. (1978). Firmness and colour of the fruit of some tomato cultivars from various sources during storage. *Journal of the Science of Food and Agriculture*, *29*, 534-538.

Gould, W.A. (1999). *Potato Production, Processing and Technology*. Maryland: CTI Publications.

Green, B.G. (2004). Oral Chemesthesis: An integral component of flavour. In: *Flavour Perception* (edited by A.J. Taylor and D.D. Roberts). Pp. 151-171. Oxford: Blackwell Publishing.

Grierson, D. and Kader, A.A. (1986). Fruit ripening and quality. In: *The Tomato Crop: A Scientific Basis For Improvement* (edited by J.G. Atherton and J. Rudich). Pp. 260-267. London: Chapman and Hall.

Gullino, M.L., Albajes, R. and Van Lenteren, J.C. (1999). Setting stage characteristics of protected cultivation and tools for sustainable crop protection. In: *Integrated pest and disease management in green houses* (edited by Albajes, R., Gullino, M.L., Van Lenteren, J.C. and Elad, Y.). Pp. 1-15. Netherlands: Kluwer Academic Publishers

Gutierrez, J., Bourke, P., Lonchamp, J. and Barry-Ryan, C. (2009). Impact of essential oils on the microbiological, organoleptic and quality markers of minimally processed vegetables. *Innovative Food Science and Emerging Technologies, 10* (2), 195-202.

Haglund Å., Johansson L., Berglund L., and Dahlstedt L. (1999). Sensory evaluation of carrots from ecological and conventional growing systems. *Food Quality and Preference, 10*, 23-9.

Hajšlová, J., Schulzová, V., Slanina, P., Janné, K., Hellenäs, K.E. and Andersson, CH. (2005). Quality of organically and conventionally grown potatoes: Four-year study of micronutrients, metals, secondary metabolites, enzymic browning and organoleptic properties. *Food Additives and Contaminants*, *22* (6), 514-534.

Hansen, H. (1981). Comparison of chemical composition and taste of biodynamically and conventionally grown vegetables. *Plant Foods Human Nutrition, 30,* 203-211.

Harborne, J.B. (1990). The chemical basis of plant defense. In: *Plant defences against mammalian herbivory* (edited by Palo, R.T. and Robbins, C.T.). Pp.45-60. Florida: CRC Press.

Harris, P.M. (1992) Mineral nutrition. In: *The Potato Crop: The Scientific Basis for Improvement* (edited by P.M Harris). Pp. 162-213. London: Chapman and Hall.

Harrison, H.C., Bergman, E.L. and Cole, R.H. (1982). Critical nutrient ranges for potassium in potato leaves and petioles. *Journal of Horticultural Science*, *64*, 47-51.

Hartman, W.M. (1997). *Signals, sounds and sensations.* New York: Springer

Haverkort, A.J. (1990). Ecology of potato cropping systems in relation to latitude and altitude. *Agricultural Systems, 32*, 251-272.

Hayase, F., Chung, T.Y. and Kato, H. (1984). Changes of volatile components of tomato fruits during ripening. *Food Chemistry, 14,* 113-124.

Heath H.B. and Reineccius, G. (1986). *Flavour chemistry and technology*. London: Macmillan.

Heatherbell, D.A. and Wrolstad, R.E. (1971). The enzymatic regeneration of volatile flavor components in carrots. *Journal of Agricultural and Food Chemistry*, *19,* 281-284.

Heaton, S. (2001). Organic farming, food quality and human health. A review of the evidence. Pp. 88. Bristol: Soil Association.

Heeb, A., Lundegårdh, B., Ericsson, T. and Savage, G. (2005). Nitrogen form affects yield and taste. *Journal of the Science of Food and Agriculture, 85*, 1405-1414.

Heeb, A., Lundegårdh, B., Savage, G. and Ericsson, T. (2006). Impact of organic and inorganic fertilisers on yield, taste, and nutritional quality of tomatoes. *Journal of Plant Nutrition and Soil Science, 169*, 535-541.

Herrera, J.L.B., Pérez, M.P.Y., Turon, J.G., Texidó, L.L., Vilaseca, C., Chifoni, A. and Chifoni, E. (1999). *Handbook of Agriculture*. New York: Marcel Dekker.

Hessayon, D.G. (2005). *The vegetable and herb expert*. New York: Expert Books.

Hijmans, R.J. (2003). The effect climate change on global potato production. *American Journal of Potato Science*, 8, 271-280.

Hijmans, R.J., Condori, B., Carrillo, R. and Kropff, M.J. (2003). A quantitative and constraint specific method to assess the potential impact of new agricultural technology: the case of frost resistant potato for the Altiplano (Peru and Bolivia). *American Journal of Potato Science*, 8, 271-280.

Hirokawa, K. and Yamazawa, K. (2008). Gendered information on sensory, hedonic and familiarity ratings of green tea by female Japanese students. *Appetite, 51*, 343-346.

Hochberger, J.E. (1964). *Perception*, Englewood Cliffs, New Jersey: Prentice Hall.

Hogstad, S., Risvik, E. and Steinsholt, K. (1997). Sensory quality and chemical composition in carrots: A multivariate study. *Acta Agriculturae Scandinavia, Section B-Plant Soil Science, 47* (4), 253-264.

Hollowood, T.A., Linforth, R.S.T. and Taylor, A.J. (2002). The effect of viscosity on the perception of flavour. *Chemical Senses, 27*, 583-591.

Honkanen, E., Pyysalo, T. and Hirvi, T. (1980). The aroma of Finish wild raspberries (*Rubus idaeus). Zeitschrift fur Lebensmittel- Untersuchung und Forschung-European Food Research and Technology, 171*, 180-182.

Hoon, M.A., Adler, E., Lindemeier, J., Battey, J.F., Ryba, N.J. and Zuker, C.S. (1999). Putative Mammalian Taste Receptors. *Cell, 96*, 541-551.

Hornung, D.E. (2006). Nasal anatomy and the sense of smell. *Advances in Oto-Rhino-Laryngology*, *63,* 1-22.

Hornung, D.E. and Enns, M.P. (1994). The synergistic action of taste and smell components of flavor. In: *Synergy* (edited by G.G. Birch and G. Campbell-Platt). Pp. 145-154. Andover: Intercept.

Hurd, L.E., Prete, F.R., Jones, T.H., Singh, T.B., Co, J.E. and Portman, R.T. (2004). First identification of a putative sex pheromone in a preying mantid. *Journal of Chemical Ecology, 30* (1), 155-166.

Hutchings, J.B. (1999). *Food colour and appearance* (2nd ed). Gaithersburg: Springer.

IFOAM. (2009). *Critisms and frequent misconceptions about organic agriculture.* Available at: http://www.ifoam.org/growingorganic/1argumentsforoa/criticismsmisconceptions/misconceptionsno19.html (Accessed July 10, 2010).

Inwood, S.M., Sharp, J.S., Moore, R.H. and Stinner, D.H. (2009). Restaurants, chefs and local food insights drawn from application of innovative framework. *Agriculture and Human Values, 26* (3), 177-191.

Irish Potato Marketing (IPM) (2009). *Trial Results* Available at: http://www.orlapotatoes.com/trial.htm (Accessed March 16, 2008).

ISO. (2004). ISO 4120: *Sensory analysis - Methodology - Triangle Test*. Geneva: International Organisation for Standardization

ISO. (1993). ISO 8586-1: *Sensory analysis- general guidance for the selection, training and monitoring of assessors*. Geneva: International Organisation for Standardization

ISO. (1992). ISO 5492: *Sensory analysis- Glossary of terms relating to sensory analysis*. Geneva: International Organisation for Standardization

Jefferies, R.A. (1989). Water stress and leaf growth in field grown crops of potato. *Journal of Experimental Botany*, 40, 1375-1381.

Johansson, L., Haglund, A., Berglund, L., Lea, P. and Risvik, E. (1999). Preference for tomatoes as affected by sensory attributes and information about growth conditions. *Food Quality and Preference, 10* (4-5), 289-298.

Johnson, J.L. and Clydesdale, F.M. (1982). Perceived sweetness and redness in colored sucrose solutions. *Journal of Food Science, 47,* 747-752.

Kader, A.A. (2002). *Postharvest technology of horticultural crops* (3rd ed). California: University of California.

Kajiwara, T., Kenji, M. and Akakabe, Y. (1996). Biogeneration of volatile compounds via oxylipins in edible seaweeds. In: *Biotechnology for improved foods and flavours* (edited by Takeoka, G.R., Teranishi, R. Williams, D.J. and Kobayashi, A.). Pp. 146-166. Washington: American Chemical Society.

Kalua, C.M., Allen, M.S., Bedgood, D.R., Bishop, A.G., Prenzler, P.D. and Robards, K. (2007). Olive oil volatile compounds, flavour development and quality: A critical review. *Food Chemistry*, 100, 273-286.

Kazeniac, S.J. and Hall, R.M. (1970). Flavour chemistry of tomato volatiles. *Journal of Food Science, 35*, 519-530.

Keast, R.S.J., Dalton, P.H. and Breslin, P.A.S. (2004). Flavour Interactions at the Sensory Level. In: *Flavour Perception* (edited by A.J. Taylor and D.D Roberts). Pp. 228-255. Oxford: Blackwell Publishing.

Kemp, S.E., Hollowood, T. and Hort, J. (2009) *Sensory Evaluation A Practical Handbook*. Oxford:Wiley-Blackwell.

Kihlberg, I., Johansson, L., Langsrud, O. and Risvik, E. (2005). Effects of information on the liking of bread. *Food Quality and Preference, 16* (1), 25-35.

Kim, M.O. and Baltes, W. (1996). On the role of 2,3-dihydro-3,5-dihydroxy-6-methyl-4(H)-pyran-4-one in the Maillard reaction. *Journal of Agricultural Food Chemistry, 44,* 283-289.

Kim, S.I., Park, C., Ohh, M.H., Cho, H.C. and Ahn, Y.J. (2003). Contact and fumigant activities of aromatic plant extracts and essential oils against *Lasioderma* serricorne (Coleoptera: Anobiidae). *Journal of Stored Product Research, 39*, 11-19.

Kjeldsen, F., Christensen, L.P. and Edelenbos, M. (2003). Changes in volatile compounds in carrots during refrigerated and frozen storage. *Journal of Agricultural and Food Chemistry, 51* (18), 5400-5407.

Kjeldsen, F., Christensen, L.P. and Edelenbos, M. (2001). Quantitative analysis of aroma compounds in carrots (*Daucus carota* L.) cultivars by capillary gas chromatography using large volume injection technique. *Journal of Agricultural and Food Chemistry*, *49,* 4342-4348.

Kling, J.W. and Riggs, L.A. (1971). *Woodworth and Schlosberg's experimental psychology* (3rd ed). New York: Holt, Rinehart and Winston.

Koskitalo, L.N. and Ormond, D.P. (1972). Effects of sub-optimal ripening temperatures on fruit quality. *Journal of the American Society of Horticultural Science, 97* (1), 13-16.

Koza, B.J., Climi, A., Dolese, M. and Zellner, D.A. (2005). Color Enhances Orthonasal Olfactory Intensity and Reduces Retronasal Olfactory Intensity. *Chemical Senses, 30*, 643-649.

Kreutzmann, S., Thybo, A.K., Edelenbos, M. and Christensen, L.P. (2008). The role of volatile compounds on aroma and flavour perception in coloured raw carrot genotypes. *International Journal of Food Science and Technology, 43* (9), 1619-1627.

Kruidhof, H.M., Bastiaans, L. and Kropff, M.J. (2008). Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. *Weed Research, 48,* 492-502.

Krumbien, A. and Auerswald, H. (1998). Characterization of aroma volatiles in tomatoes by sensory analyses. *Nahrung, 42,* 395-399

Krumbien, A., Peters, P. and Bruckner, B. (2004). Flavour compounds and a quantitative descriptive analysis of tomatoes (*Lycopersicon esculentum* Mill.) of different cultivars in short-term storage. *Postharvest Biology and Technology, 32* (1), 15-28.

Kumar, S., Dhingra, A. and Daniell, H. (2004). Plastid-expressed *betaine aldehyde dehydrognase* gene in carrot cultured cells, root, leaves confers enhanced salt tolerance. *Plant Physiology, 136,* 2843-2854.

Kumpulainen, J. (2001). Organic and conventional foodstuffs: Nutritional and toxicological quality comparisons. *The International Fertiliser Society Proceedings*, 472, 1-20.

Kuo, P.M., Chu, F.H., Chang, S.T., Hsia, W.F. and Wang, S.Y. (2007). Insecticidal activity of essential oil from *Chamaecyparis formosensis* Matsum. *Holzforschung*, *61*, 595-599.

Lairon, D. (2009). Nutritional quality and safety of organic food: A review. *Agronomic Sustainable Development*, *30*, 33-41.

Ledel, F. (1990). Chemical pathways of the Maillard reaction. In: *The Maillard reaction in food processing, human nutrition and physiology* (edited by P.A. Finot, H.U. Aeschbacher, R.F. Hurrell and R. Liardon). Pp.19-42. Basel: Birkhauser Verlag.

Lee, S.J., Umano, K., Shibamoto, T. and Lee, K.G. (2005). Identification of volatile components in basil (*Ocimum basilicum* L.) and thyme leaves (*Thymus vulgaris* L.) and their antioxidant properties. *Food Chemistry, 91*, 131-137.

Lenfant, F., Loret, C., Pineau, N., Hartmann, C. and Martin, N. (2009). Perception of oral food breakdown. The concept of sensory trajectory. *Appetite, 52*, 659-667.

Lester, G.E. (2006). Organic versus conventionally grown produce: quality differences, and guidelines for comparison studies. *Hortscience, 41* (2), 296-300.

Linińska, G. and Leszczyński, W. (1989). *Potato Science and Technology*. Essex: Elsevier Science Publishers.

Lonchamp, J. (2006). *Volatile compounds as quality markers for leafy green ready to use vegetables: their identification and determination of origin*. PhD Thesis, Dublin Institute of Technology, Ireland.

Lonchamp, J., Barry-Ryan, C. and Devereux, M (2009). Identification of volatile quality markers of ready to use lettuce and cabbage. *Food Research International*, *42* (8), 1077-1086.

López-Camelo, A.F. and Gomez, P.A. (2004). Comparison of colour indexes for tomato ripening. *Horticultura Brasília, 22 (3)*, 534-537.

Low, M.Y., Koutsidis, G., Parker, J.K., Elmore, S.J., Dodson, A.T. and Mottram, D.S. (2006). Effect of citric acid and glycine addition on acrylamide and flavour in a potato model system. *Journal of Agricultural Food Chemistry, 54*, 5976-5983.

Luyten, H. and Van Vliet, T. (2006). Acoustic emission, fracture behavior and morphology of dry crispy foods, a discussion article. *Journal of Texture Studies, 37*, 221-240.

Maarse, H. (1991). *Volatile compounds in foods and beverages*. New York: Marcel Dekker.

Mac Connell, S. (2008). *Organic Food Sales soar 82% to €104 million*. The Irish Times: Dublin. Available at: http://www.irishtimes.com/newspaper/ireland/2008/0905/1220544890463.html. (Acessed September 5, 2008).

Maga, J.A. (1994). Potato flavour. *Food Reviews International, 10,* 1-48.

Maga, J.A. (1981). Pyridines in food. *Journal of Agricultural and Food Chemistry, 29* (5), 895-898

Maga, J.A. (1974). Influence of colour on taste thresholds. *Chemical Senses and Flavour, 1* (1), 115-119.

Maga, J.A., Moore, F.D. and Oshima, N. (1976). Yield, nitrate levels and sensory properties of spinach as influenced by organic and mineral nitrogen fertiliser levels. *Journal of the Science of Food and Agriculture, 27*, 109-114.

Maggio, A., Carillo, P., Bulmetti, G.S., Fuggi, A., Barbieri, G. and De Pascale, S. (2008). Potato yield and metabolic profiling under conventional and organic farming. *European Journal of Agronomy*, *28,* 343-350.

Magkos, F., Arvaniti, F. and Zampelas, A. (2006). Organic food: Buying more safety or just peace of mind? A critical review of the literature. *Critical Reviews in Food Science and Nutrition*. *46,* 23-56.

Magkos F, Arvaniti, F. and Zampelas, A. (2003). Putting the safety of organic food into perspective. *Nutrition Research Reviews, 16*, 211-21

Makatouni, A. (2002). What motivates consumers to buy organic food in the U.K? Results from a qualitative study. *British Food Journal*, *104*, 345-352.

Martín-Luengo, M.A., Yates, M., Martínez-Domingo, M.J., Casal, B., Iglesias, M., Esteban, M. and Ruiz-Hitzky, E. (2008). Synthesis of *p*-cymene from limonene, a renewable feedstock. *Applied Catalysis B: Environmental*, *81*, 218-224.

Matteson, P.C. (2000). Insect pest management in tropical Asian irrigated rice. *Annual Review of Entomology*, 45, 549-574.

Maul, F., Sargent, S.A., Balaban, M.O., Baldwin, E.A, Huber, D.J. and Sims, C.A (1998). Aroma volatile profiles from vine ripened tomatoes are influenced by physiological maturity at harvest: an application of the electric nose technology. *Journal of American Society of Horticultural Science*, *123*, 1094-1101.

Meilgaard, M.C., Civille, G.V. and Carr, B.T. (2007). *Sensory Evaluation Techniques*, (4th ed). Boca Raton: CRC Press.

Met Éireann (2009). *Monthly Weather Summaries May-October 2007*. Dublin: Met Éireann. Available at: http://www.met.ie/agri-environment/agri_agri.asp (Accessed May 20, 2009).

Mioche, L. And Peyron, M.A. (1995). Bite force displayed during assessment of hardness in various texture contexts. *Archives of Oral Biology, 40*, 415-423.

Monaghan, G. (2010). *Organic spuds taste no better, test reveals*. Available at: http://www.timesonline.co.uk/tol/news/world/ireland/article7069901.ece (Accessed on July 10, 2010).

Monaghan, G. (2009). *Richard Corrigan roasts organic research*. Available at: http://www.timesonline.co.uk/tol/news/world/ireland/article6736280.ece (Accessed on July 10, 2010).

Montagu, K.D. and Goh, K.M. (1990). Effects of forms and rates of organic and inorganic nitrogen fertilisers on yield and some quality indices of tomatoes (*Lycoperiscon esculentum,* Mill). *New Zealand Journal of Crop Horticultural Science, 18*, 31-37.

Montouto-Graña, M., Fernández-Fernández, E., Vázquez-Odériz, M.L. and Romero-Rodríguez, M.A. (2002). Development of a sensory profile for specific denomination “Galician potato”. *Food Quality and Preference, 13*, 99-106.

Morrot, G., Brochet, F. and Dubourdieu, D. (2001). The color of odors. *Brain and Language, 79*, 309-320.

Murray, E.A. and Richmond, B.J. (2001). Role of perirhinal cortex in object perception, memory and associations. *Current Opinions in Neurobiology, 11*, 188-193.

National Consumer Agency of Ireland (2010). Shopping and pricing- household budgeting and impact of the recession. Available at: http://www.nca.ie/eng/Research_Zone/Reports/NCA-research-shopping-and-recession-jan2010.doc (Accessed January 6, 2010).

Nielsen, S.S. (2003). *Food Analysis* (3rd ed). New York: Kluwer Academic/ Plenum Publisher.

Nishibori, S. and Kawakishi, S. (1990). Effects of dough materials on flavour formation in cookies. *Journal of Food Science, 55* (1), 409-412.

NIST (1998). *Mass Spectral Library*. Gaithersburg: National Institute of Standards and Technology.

Nonnecke, I.B.L. (1989) *Vegetable Production*. New York: Van Nostrand Reinhold.

Nursten, H.E. (2005). *The Maillard reaction: chemistry, biochemistry and implications*. Cambridge: Royal Society of Chemistry.

Nyman, E.M.G-L., Svanberg, S.J.M., Andersson, R. and Nilsson, T. (2005). Effects of cultivar root weight, storage and boiling on carbohydrate carrots (*Daucus carota* L). *Journal of the Science of Food and Agriculture, 85* (3), 441-449.

O'Beirne, D. and Cassidy, J.C. (1990). Effects of nitrogen fertiliser on yield, dry matter content and flouriness in potatoes. *Journal of the Science of Food and Agriculture*, 52 (3), 351-363.

Ohloff, G. and Flament. I. (1979). The role of heteroatomic substances in the aroma compounds of foodstuffs. *Fortschritte der Chemie Organischer Naturstoffe, 36*, 231-253.

Organic Matters (2009). *What do organic growers do about insecticides*. Available at: http://www.organicmattersmag.com/features/92-what-do-organic-growers-do-about-insecticides (Accessed September 25, 2009).

Oruna-Concha, M.J., Bakker, J. and Ames, J.M. (2002). Comparison of the volatile components of two cultivars of potato cooked by boiling, conventional baking and microwave baking. *Journal of the Science of Food and Agriculture, 82*, 1080-1087.

O'Rourke, C. (2008). *Organic Food-Fact or Fiction*. Food Safety of Ireland Consultative Council Meeting: Alexandra Hotel: Dublin.

O'Sullivan, M.G., Byrne, D.V., Martens, H., Gidskehaug, L.H., Andersen, H.J. and Martens, M. (2003). Evaluation of Pork Colour: Prediction of visual sensory quality of meat from instrumental and computer vision methods of colour analysis. *Meat Science*, *65*, 909-918.

Padel, S. and Foster, C. (2005). Exploring the gap between attitudes and behaviour: Understanding why consumers buy or do not buy organic food. *British Food Journal*, *107* (8), 606-625.

Padel, S., Schaack, D. and Willer, H. (2009). Development of the Organic Market in Europe. In: *The World of Organic Agriculture. Statistics and Emerging Trends* (edited by H. Willer and L. Kilcher). Pp. 155-163. Bonn: International Federation of Organic Agricultural Movement.

Pangborn, R.M. and Szczesniak, A.S. (1973). Effect of hydrocolloids on oral viscosity and basic taste intensities. *Journal of Texture Studies*, *4*, 224-241.

Pardo, J.E., Alvarruiz, A., Pérez, J.I., Gómez, R. and Varón, R. (2000). Physical-chemical and sensory quality evaluation of potato varieties (*Solanum tuberosum* L.). *Journal of Food Quality*, *23*, 149-160.

Park, Y.W. (1996). Moisture and Ash Contents of Food. In: *Handbook of Food Analysis* (edited by L.M.L. Nollet). Pp. 68-73. New York: Marcel Dekker Inc.

Pasqua, G., Monacelli, B. and Silvestrini, A. (2003). Accumulation of essential oils in relation to root differentiation in *Angelic archangelica* L. *European Journal of Histochemistry*, *47* (1), 87-90.

Péneau, S., Hoehn, E., Roth, H.R., Escher, F. and Nuessli, J. (2006). Importance of consumer perception of the freshness of apples. *Food Quality and Preference, 17,* (1-2), 9-9.

Pernollet, J.C. and Briand, L. (2004). Structural recognition between odorants, olfactory binding proteins and olfactory receptors-First events in odour coding. In: *Flavour Perception* (edited by A.J. Taylor and D.D. Roberts). Pp. 86-150. Oxford: Blackwell

Petersen, K.K., Willumsen, J. and Kaack, K. (1998). Composition and taste of tomatoes as affected by increased salinity and different salinity source. *Journal of Horticultural Science and Biotechnology, 73*, 205-215.

Petró-Turza, M. (1987). Flavour of tomato and tomato products. *Food Reviews. International*, *2*, 309-351.

Peyron, M.A., Maskawi, K., Woda, A., Tanguay, R. and Lund, J.P. (1997). Effects of food texture and sample thickness on mandibular movement and hardness assessment during biting in man. *Journal of Dental Research*, *76* (3), 789-795.

Pittet, A.O. and Hruza, D.E. (1974). Comparative study of flavour properties of thiazole derivatives. *Journal of Agricultural and Food Chemistry*, *22* (2), 264-269

Pope, C. (2009). Is organic worth it? *The Irish Times*, 14 September, p15.

Porretta, S. (1994). Qualitative comparison between commercial "traditional" and "organic" tomato products using multivariate statistical analysis. *Acta Horticulturae*, *376*, 259-270.

Prescott, J. (1999). Flavour as a psychological construct: implications for perceiving and measuring sensory qualities of foods. *Food Quality and Preference, 10,* 349-356.

Prescott, J., Allen, S. and Stephens, L. (1993). Interactions between oral chemical irritation taste and temperature. *Chemical Senses, 18*, 389-404.

Prescott, J. and Stevenson, R.J. (1995). Effects of oral chemical irritation on tastes and flavours in frequent and infrequent users of chilli. *Physiology and Behaviour, 58*, 1117-1127.

Prestage, S., Linforth, R.S.T., Taylor, A.J., Lee, E., Speirs, J., and Schuch, W. (1999). Volatile production in tomato fruit, with modified alcohol dehydrogenase activity. *Journal of the Science of Food and Agriculture*, *79* (1), 131-136.

Rader, J.S., Walser, R.H., Williams, C.F. and Davis, T.D. (1985). Organic and conventional peach production. *Biological Agriculture and Horticulture, 2*, 215-222.

Radman, R. (2005). Consumer consumption and perception of organic products in Croatia. *British Food Journal*, *107* (4), 263-273.

Rawson, N.A. and Li, X. (2004). The cellular basis of flavour perception: taste and aroma. In: *Flavour Perception* (edited by A.J. Taylor and D.D Roberts). Pp. 57-85. Oxford: Blackwell Publishing.

Re, L., Maurer, C. and Ohloff, G. (1973). A simple synthesis of 4-hydroxy-2,5-dimethyl-3(2H)-furanone (furaneol), an important aroma component of pineapple and strawberry. *Helvetica Chimica Acta, 56,* 1882-1884.

Redmond, G.A., Gormley, T.R. and Butler, F. (2004). The effect of short and long term freeze-chilling on the quality of cooked beans and carrots. *Innovative Food Science and Emerging Technologies*, *5* (1), 65-72.

Reid, L.M., O'Donnell, C.P. and Downey, G. (2004). Potentional of SPME GC and Chemoretics to detect adultration of soft fruit purees. *Journal of Agricultural and Food Chemistry, 52*, 421-427.

Reineccius, G. (2006). *Flavour Chemistry and Technology* (2nd ed). Boca Raton: Taylor and Francis Group.

Reyes, L.F., Miller, J.C. and Cisneros-Zevellos, L. (2004). Environmental conditions influence content and yield of antocyanins and total phenolics in purple and red flesh potatoes during tuber development. *American Journal of Potato Research, 81*, 187-193.

Rhee, K.S. and Watts, B.M. (1966). Effects of antioxidants on lipoxygenase activity in model systems and pea (*Pisum sativum*) slurries. *Journal of Food Science, 31*, 669-674.

Rocha, A.M.C.N., Mota, C.C.A.R. and Morais, A.M.M.B. (2007). Physicochemical qualities of minimally processed carrots stored under vacuum. *Journal of Foodservice, 18*, 23-30.

Rodin, J.O., Himel, C.M., Silverstein., R.M., Leeper, R.W. and Gortner, W.A. (1965). Volatile flavour and aroma components of pineapple 1. Isolation and tentative identification of 2,5-dimethyl-4-hydroxy-3(2H)-furanone. *Journal of Food Science, 30* (2), 280-285.

Rodríguez-Sevilla, D.M., Villanueva-Suarez, M.J. and Redondo-Cuenca, A. (1999). Effects of processing conditions on soluble sugars content of carrot, beetroot and turnip. *Food Chemistry, 66* (1), 81-85.

Roitner-Schobesberger, B., Darnhofer, I., Somsook, S. and Vogl, C.R. (2008). Consumer perceptions of organic foods in Bangkok, Thailand. *Food Policy, 33,* 112-121.

Rosahl, S. (1996). Lipoxygenase in plants: their role in development and stress response. *Zeitschrift für Nauturforschung, 51*, 123-138.

Rosenfeld, H.J., Aaby, K. and Lea, P. (2002). Influence of temperature and plant density on sensory quality and volatile terpenoids of carrots (*Daucus carota* L) root. *Journal of the Science of Food and Agriculture*, 82, (12), 1384-1390.

Rosenfeld, H.J., Risvik, E., Samuelsen, R.T. and Rødbotten, M. (1997). Sensory profiling of carrots from northern latitudes. *Food Research International*, *30* (8), 593-601.

R.T.E. (2009). *Golden delicious apple claufoutis with Derry Clarke.* Available at:http://www.rte.ie/tv/theafternoonshow/2009/0922/food774.html (Accessed July 10, 2010).

Rubatzky, V.E. and Yamaguchi, M. (1997). *World Vegetables: Principles, production and nutritive values* (2nd ed). New York: Chapman and Hall.

Saba, A. and Messina, F. (2003). Attitudes towards organic foods and risk/benefit perception associated with pesticides. *Food Quality and Preference, 14* (8), 637-645.

Sahota, A. (2009). The Global Market for Organic Food and Drink. In: *The World of Organic Agriculture. Statistics and Emerging Trends* (edited by H. Willer and L. Kilcher). Pp. 59-63. Bonn: International Federation of Organic Agricultural Movement.

Sánchez-Moreno, C., Plaza, L., De Ancos, B. and Cano, M.P. (2006). Impact of high pressure and traditional thermal processing of tomato puree on carotenoid, vitamin C and antioxidant activity. *Journal of the Science of Food and Agriculture, 86*, 171-179.

Sanz, C., Olías, J.M. and Pérez, A.G. (1997). Aroma biochemistry of fruits and vegetables. In: *Phytochemistry of fruit and vegetables* (edited by F.A. Tomás-Barberán and R.J. Robins). Pp. 130. New York: Oxford University Press Inc.

Sato, S., Sakaguchi, S., Furukawa, H. and Ikeda, H. (2006). Effects of NaCl application to hydroponic nutrient solution on fruit characteristics of tomato (*Lycopersicon esculentum* Mill). *Scientia Horticulturae, 109*, 248-253.

Schaack, D. (2009). Five Percent More Organic Land in the EU-27- All Crops on the Increase. In: *The World of Organic Agriculture. Statistics and Emerging Trends* (edited by H. Willer and L. Kilcher). Pp. 152-154. Bonn: International Federation of Organic Agricultural Movement.

Schaller, R.G. and Schnitzler, W.H. (2000). Nitrogen nutrition and flavour compounds of carrots (*Daucus carota* L) cultivated in Mitscherlich pots. *Journal of the Science of Food and Agriculture*, *80*, 49-56.

Schuphan, W. (1974). Nutritional value of crops as influenced by organic and inorganic fertiliser treatments. *Plant Foods Human Nutrition*, *23*, 333-388.

Seifert, R.M. and Buttery, R. G. (1978). Characterization of some previously unidentified sesquiterpenes in carrot root. *Journal of the Science of Food and Agriculture*, *26*,181-183.

Seljåsen, R., Bengtsson, G., Hoftun H. and Vogt, G. (2001). Sensory and chemical changes in five varieties of carrots (*Daucus carota* L.) in response to mechanical stress at harvest and postharvest. *Journal of the Science of Food and Agriculture*, *81*, 436-447.

Serrano, E., Beltran, J. And Hernandez, F. (2009). Application of multiple headspace-solid-phase micro extraction followed by gas chromatography mass spectrometry to quantitative analysis of tomato compounds. *Journal of Chromatography A*, 1216, 127-133.

Shamaila, M., Durance, T. and Girard, B. (1996). Water blanching effects on the headspace volatiles and sensory attributes of carrots. *Journal of Food Science, 61*, 1191-1195.

Shankar, M.U., Levitan, C.A. and Spence, C. (2010). Grape expectations: The role of cognitive influences in color-flavor interactions. *Consciousness and Cognition, 19,* 380-390.

Shinoda, Y., Komura, H., Homma, S. and Murata, M. (2005). Browning of model orange juice solutions affecting the formation of decomposition products. *Bioscience, Biotechnology and Biochemistry, 69* (11), 2129-2137.

Siegrist, M. and Cousin, M.E. (2009). Expectations influence sensory experience in a wine tasting. *Appetite, 52*, 762-765.

Simon, P.W. and Lindsay, R.C. (1983). Effects of processing upon objective and sensory variables of carrots. *Journal of the American Society for Horticultural Science, 108*, 928-931.

Simon, P.W., Peterson. C.E. and Lindsay, R.C. (1980). Correlations between sensory and objective parameters of carrot flavour. *Journal of Agricultural and Food Chemistry*, *28,* 559-562.

Sköld, M., Karlberg, A.T., Matura, M. And Börje, A. (2006). The fragrance chemical β-caryophyllene-air oxidation and skin sensitisation. *Food and Chemical Toxicology, 44, 538-545*.

Smith, D.L. (1987). *Rockwool in Horticulture*. London: Grower Books.

Smith, D. V. and Margolskee, R.F. (2001). Making sense of taste. *Scientific American*, *284*, 32-39.

Son Vu, T., Smout, C., Sila, D.N., Van Loey, A.M.L. and Hendrickx, M.E.G. (2006). The effect of the brine ingredients on carrot texture during thermal processing in relation to pectin depolymerisation due to the elimination reaction. *Journal of Food Science, 71* (9), E370-E375.

Sonneveld, C. and Welles, G.W.H. (1988). Yield and quality of rockwool tomatoes as affected by variations in EC-value and climatic conditions. *Plant Soil*, *111*, 37-42

Statutory Instrument. (2009). *European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2009*, SI. No.101 of 2009.

Statutory Instrument. (2007). *European Communities (Organic Farming) (Ammended) Regulations 2007*, S.I. 698 of 2007.

Stevenson, R.J., Prescott, J. and Boakes, R.A. (1999). Confusing tastes and smell: How odours can influence the perception of sweet and sour tastes. *Chemical Senses*, *24*, 627-635.

Stommel, J., Abbott, J.A., Saftner, R.A. and Camp. M.J. (2005). Sensory and objective quality attributes of beta-carotene and lycopene rich tomato fruit. *Journal of the American Society of Horticultural Science, 130* (2), 244-251.

Storey, M. (2007). The Harvested Crop. In: *Potato Biology and Biotechnology- Advances and Perspectives* (edited by D. Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D.L. MacKerron, M.A. Taylor and H.A. Ross). Pp. 441-470. Oxford: Elsevier.

Sugisawa, H., Nakamura, K. and Tamura, H. (1990). The aroma profile of the volatiles in marine green algae (*Ulva pertusa*). *Food Reviews International, 6* (4), 573-89.

Suojala, T. (2000). Variation in sugar content and composition of carrot storage roots at harvest and during storage. *Scientia Horticulturae, 85*, 1-19.

Svanberg, S.J.M., Nyman, E.M.G-L., Andersson, R. and Nilsson, T. (1997). Effects of boiling and storage on dietary fibre and digestible carbohydrates in various cultivars of carrots. *Journal of the Science of Food and Agriculture*, *73* (2), 245-254.

Szymczak, P., Gajewski, M., Radzanowska, J. and Dabrowska, A. (2007). Sensory quality and consumer liking of carrot cultivars of different genotype. *Vegetable Crop Research Bulletin, 67*, 163-176.

Taverne, D. (2005). *The march of unreason: science, democracy and the new fundamentalism*. New York: Oxford University Press.

Taylor, A.J. and Hort, J. (2004). Measuring proximal stimuli involved in flavour perception. In: *Flavour Perception* (edited by A.J. Taylor and D.D Roberts). Pp. 1-39. Oxford: Blackwell Publishing.

Taylor, M.A., McDougall, G.J. and Stewart, D. (2007). In: *Potato Biology and Biotechnology- Advances and Perspectives* (edited by D. Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D.L. MacKerron, M.A. Taylor and H.A. Ross). Pp. 525-538. Oxford: Elsevier.

Teagasc. (2008). *Guideline for organic farming*. Dublin: Teagasc. Available at: http://www.foodassurance.teagasc.ie/NR/rdonlyres/E680DD92-CED8-4FEC-9199-66F0B60E9477/80/OrganicLeaflet.pdf. (Accessed September 30, 2008).

Teagasc. (2007a). Potential for organic tillage in Ireland. Dublin: Teagasc Available at: http://www.teagasc.ie/publications/2007/20070131/ntc2007paper07.asp
(Accessed August 25, 2009).

Teagasc. (2007b) Breeding new potato varieties Dublin: Teagasc Available at: http://www.teagasc.ie/publications/ tresearch/tresearch200702.pdf (Accessed August 25, 2009).

Termine, E., Lairon, D., Taupier-Letage, B., Gautier, S., Lafont, R. and Lafont, H. (1987). Yield and content in nitrates, minerals and ascorbic acid of leeks and turnips grown under mineral or organic nitrogen fertilisations. *Plant Foods Human Nutrition*, *37*, 321-332.

The New Ecologist. (2010). *Living green with organic vegetables.* Available from: http://www.thenewecologist.com/2010/05/living-green-with-organic-vegetables/ (Accessed July 10, 2010).

The Organic Centre (2009) *Tomato Hybrid*. Available from: http://www.theorganic centre.ie/catalog/108/tomatohybrid (Accessed September 25, 2009).

Theuer, R.C. (2006). *Do organic fruits and vegetables taste better than conventional fruits and vegetables?* The Organic Centre. Available at: http://www.organicagcentre.ca/Docs /OrganicCentreTaste06.pdf (Accessed September 25, 2009).

Thompson, A.K. (1996). *Postharvest Technology of Fruit and Vegetables*. Oxford: Blackwell Science.

Thybo, A.K., Bechmann, I.E. and Brandt, K. (2005). Integration of sensory and objective measurements of tomato quality: Quantitative assessment of the effect of harvest data as compared with growth medium (soil versus rockwool), EC, variety, and maturity. *Journal of the Science Food and Agriculture*, *85*, 2289-2296.

Thybo, A.K., Edelenbos, M., Christensen, L.P., Sorensen, J.N. and Thorup-Kristensen, K. (2006). Effect of organic growing systems on sensory quality and chemical composition of tomatoes. *Lebensmittel Wissenschaft un Technologie-Food Science and Technology*, *39*, 835-843.

Thybo, A.K. and Martens, M., (2000). Analysis of sensory assessors in texture profiling of potatoes by multivariate modelling. *Food Quality and Preference*, *11*, 283-288.

Tomes, M.L. (1963). Temperature inhibition of carotene synthesis in tomato. *Botanical Gazette*, *124* (3), 180-185.

Tregear, A., Dent, J.B. and McGregor, M.J. (1994). The demand for organically grown produce. *British Food Journal*, *96* (4), 21-25.

Tressl, R., Holzer, M. and Apetz, M. (1975). The formation of vegetable aroma from major food components. In: *Aroma Research* (edited by H. Maarse and P.J. Groenen). Pp. 41. Wageningen: Pudoc.

Turkmen, N., Ferda, S. and Velioglu, Y.S. (2005). The effect of cooking methods on total phenolics and antioxidant activity of selected green vegetables. *Food Chemistry, 93* (4), 713-718.

Vainburg, V.M., Lysenko, A.A., Shtyagina, L.M., Illarinova, E.L., Chufaroskaya, T.I and Sverdlova, N.I. (2008). Fibrous materials as artificial soil substrates. *Fibre Chemistry, 40* (4), 308-313.

Van Ruth, S.M., O'Connor, C.H. and Delahunty, C.M. (2000). Relationships between temporal release of aroma compounds in a model mouth system and their physico-chemical characteristics. *Food Chemistry, 71*, 393-399.

Van Ruth, S.M. and Roozen, J.P. (2002). Delivery of flavours from food matrices. In: *Food Flavour Technology* (edited by A.J. Taylor). Pp. 167-184. Sheffield: Academic Press.

Van Ruth, S.M. and Roozen, J.P. (2000). Influence of matiscation and saliva on aroma release in a model mouth system. *Food Chemistry, 71* (3), 339-345.

Van Vliet, T., Van Aken, G.A., De Jongh, H.H.J. and Hamer, R.J. (2009). Colloidal aspects of texture perception. *Advances in Colloid and Interface Science, 150*, 27-40.

Varming, C., Jensen, K., Møller, S., Brockhoff, P.B., Christiansen, T., Edelenbos, M., Bjorn, G.K. and Poll, L. (2004). Eating quality of raw carrots-correlations between flavor compounds, sensory profiling analysis and consumer liking test. *Food Quality Preference, 15*, 531-540.

Vernin, G. and Parkanyi, C. (1982). Mechanisms for the formation of heterocyclic compounds in Maillard and pyrolyses reactions. In: *Chemistry of Heterocyclic Flavourings and Aroma Compounds* (edited by G. Vernin). Pp. 151. Chichester: Ellis Horwood.

Verhagen, J. and Engelen, L. (2006). The neurocognitive bases of human multimodal food perception: Sensory integration. *Neuroscience and Behavioral Reviews, 30*, 613-650.

Vickers, Z.M. (1984). Crispness and Crunchiness- a difference in pitch? *Journal of Texture studies*, *15* (2), 157-163.

Visschers, R.W., Jacobs, M.A., Frasnelli, J., Hummel, T.M Burgering, M. and Boelrijk, A.E.M. (2006). Cross-modality of texture and aroma perception is independent of orthonasal and retronasal stimulation. *Journal of Agriculture and Food Chemistry*, *54*, 5509-5515.

Vogtmann, H., Matthies, K., Kehres, B. and Meier-Ploeger, A. (1993). Enhanced food quality: effects of compost on the quality of plant foods. *Compost Science and Utilization, 1*, 82-100.

Voirol, E. and Dagnet, N. (1989). Direct nasal and oronasal profiling of meat flavouring: Influence of temperature, concentration and additives. *Lebensmittel-Wissenchaft Technologie, 22*, 399-405.

Vos, J. and Haverkort, A.J. (2007). Water availability and potato crop performance. In: *Potato Biology and Biotechnology- Advances and Perspectives* (edited by D. Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D.L. MacKerron, M.A. Taylor and H.A. Ross). Pp. 333-351. Oxford: Elsevier.

Vreugdenhil, D., Bradshaw, J., Gebhardt, C., Govers, F., MacKerron, D.L., Taylor, M.A. and Ross H.A. (2007). *Potato Biology and Biotechnology- Advances and Perspectives*. Oxford: Elsevier.

Walshe, B.E., Sheehan, E.M., Delahunty, C. M., Morrissey, P.A. and Kerry, J. P. (2006). Composition, sensory and shelf life stability analyses of *Longissimus dorsi* muscle from steers reared under organic and conventional production systems. *Meat Science, 73,* 319-325.

Wang, Y. and Kays, S.J. (2000). Effect of cooking method on the aroma constituents of sweet potatoes (*Ipomoea Batatas* L.). *Journal of Food Quality, 24* (1), 67-87.

Wang, C., Xing, J., Chin, C.K., Ho, C.T. and Martin, C.E. (2001). Modification of fatty acids changes the flavor volatiles in tomato leaves. *Phytochemistry, 58*, 227-232.

Wansink, B. and Park, S.B. (2002). Suggestiveness and labelling: do soy labels biase taste? *Journal of Sensory Studies*, *17* (5), 483-491.

Wansink, B., Payne, C.R. and North, J. (2007). Fine as North Dakota wine: sensory expectations and the intake of comparison food. *Physiology and Behavior, 96*, 712-716.

Weaver, C. (2003). *The Food Chemistry Laboratory: A Manual for Experimental Foods*. Boca Raton: CRC Press.

White, P.J., Broadley, M.R., Hammond, J.P. and Thompson, A.J. (2005). Optimising the potato root system for phosphorus and water acquisition in low input growing systems. *Aspects of Applied Biology*. *73,* 111-118.

Willer, H. (2009). Europe: Overview. In: *The World of Organic Agriculture. Statistics and Emerging Trends* (edited by H. Willer and L. Kilcher). Pp. 148-151. Bonn: International Federation of Organic Agricultural Movement.

Willer, H., Rohwedder, M. and Wynen, E. (2009). Organic Agriculture Worldwide: Current Statistics. In: *The World of Organic Agriculture. Statistics and Emerging Trends* (edited by H. Willer and L. Kilcher). Pp. 25-58. Bonn: International Federation of Organic Agricultural Movement.

Winch, T. (2007). *Growing food: a guide to food production*. Dordrecht: Springer.

Winter, C.K. and Davis, S.F. (2006). Organic food. *Journal of Food Science, 71* (9), R117-R124.

Woese, K., Lange, D., Boess, C. and Bögl, K.W. (1997). A comparison of organically and conventionally grown foods-Results of a review of the relevant literature. *Journal of the Science of Food and Agriculture, 74* (3), 281-293.

Wright, D.H. and Harris, N.D. (1985). Effect of nitrogen and potassium fertilisation on tomato flavor. *Journal of Agricultural and Food Chemistry, 33* (3), 355-358.

Wrolstad, R.E., Acree, T.E., Decker, E.A., Penner, M.H., Reid, D.S., Schwartz, S.J., Shoemaker, C.F., Smith, D.M. and Sporns, P. (2005). *Handbook of Food Analytical Chemistry*, New Jersey: Wiley-Inter Science.

Wszelaki, A.L., Delwiche, J.F., Walker, S.D., Liggett, R.E., Scheerens, J.C. and Kleinhenz, M.D. (2005). Sensory quality and mineral and glycoalkaloid concentrations in organically and conventionally grown redskin potatoes (*Solanum tuberosum*). *Journal of the Science of Food and Agriculture, 85*, 720-726.

Wu, M. and Kubota, C. (2008). Effects of high electrical conductivity of nutrient solution and its application on lycopene, chlorophyll and sugar concentrations of hydroponic tomatoes during ripening. *Scientia Horticulturae, 116*, 122-129.

Yilmaz, E. (2000). The chemistry of fresh tomato flavour. *Turkish Journal of Agriculture and Forestry, 25*, 149-155.

Yu, M.H., Olson, L.E. and Salunkhe, D.K. (1968). Production of 3-methyl butanal from L-leucine by tomato extract. *Plant Cell Physiology, 9*, 633-638.

Zabetakis, I., Grimshaw, J.W. and Robinson, D.S. (1996) The biosynthesis of 2,5-dimethyl-4-hydroxy-3(2H)-furanone and its derivatives in strawberry aroma. In: *Flavour Science Recent Developments* (edited by A.J. Taylor and D.S. Mottram). Pp. 92. Cambridge: Royal Society of Chemistry.

Zampini, M., Sanabria, D., Phillips, N. and Spence, C. (2007). The multisensory perception of flavor: Assessing the influence of color cues on flavor discrimination responses. *Food Quality and Preference, 18,* 975-984.

Zampini, M. and Spence, C. (2004). The role of auditory cues in modulating the perceived crispiness and staleness of potato chips. *Journal of Sensory Studies, 19*, 347-363.

Zampini, M., Wantling, E., Phillips, N. and Spence, C. (2008). Multisensory flavor perception: Assessing the influence of fruit acids and color cues on the perception of fruit flavoured beverages. *Food Quality and Preference, 19,* 335-343.

Zellner, D.A. and Durlach, P. (2003). Effect of colour on expected and experienced refreshment, intensity and liking of beverages. *American Journal of Psychology, 104*, 547-561.

Zellner, D.A. and Whitten, L.A. (1999). The effect of color intensity and appropriateness on color induced odour enhancement. *American Journal of Psychology*, *112* (4), 585-604.

Zhao, X., Chambers IV, E., Matta, Z., Loughin, T.M. and Carey, E.E. (2007). Consumer sensory analysis of organically and conventionally grown vegetables. *Journal of Food Science*, *72* (2), S87-S91

APPENDICES

Appendix A: Volatiles previously identified in carrots, potatoes and tomatoes

Aroma Volatile	**Authors**
α-pinene	Simon *et al.,* 1980; Schaller and Schnitzler *et al.,* 2000;Wang *et al*., 2001; Kjeldsen *et al.,* 2001; Kjeldsen *et al.,* 2003;Cliffe-Byrnes *et al*., 2007; Kreutzmann *et al.,* 2008
β-pinene	Simon *et al.,* 1980;Kjeldsen *et al.,* 2001;Kjeldsen *et al.,* 2003;Buttery and Takeoka, 2004; Cliffe-Byrnes *et al*., 2007; Kreutzmann *et al.,* 2008; Gutierrez *et al.,* 2009
Sabiene	Simon *et al.,* 1980; Schaller and Schnitzler *et al.,* 2000;Wang *et al*., 2001; Kjeldsen *et al.,* 2001; Kreutzmann *et al.,* 2008
Limonene	Schaller and Schnitzler *et al.,* 2000;Wang *et al*., 2001; Kjeldsen *et al.,* 2001; Cliffe-Byrnes *et al*., 2007; Kreutzmann *et al.,* 2008; Lonchamp *et al.,* 2009
β-phellandrene	Krumbien and Auerswald, 1998; Kjeldsen *et al.,* 2001; Wang *et al*., 2001
γ-terpinene	Simon *et al.,* 1980;Kjeldsen *et al.,* 2001;Kjeldsen *et al.,* 2003;Buttery and Takeoka, 2004; Cliffe-Byrnes *et al*., 2007; Kreutzmann *et al.,* 2008; Gutierrez *et al.,* 2009
p-cymene	Simon *et al.,* 1980;Kjeldsen *et al.,* 2001;Kjeldsen *et al.,* 2003;Buttery and Takeoka, 2004; Cliffe-Byrnes *et al*., 2007; Kreutzmann *et al.,* 2008; Gutierrez *et al.,* 2009
Terpinolene	Simon *et al.,* 1980;Kjeldsen *et al.,* 2001;Kjeldsen *et al.,* 2003;Buttery and Takeoka, 2004; Cliffe-Byrnes *et al*., 2007; Kreutzmann *et al.,* 2008
α-bergamotene	Seifert and Buttery, 1978; Kjeldsen *et al.,* 2003
Caryophyllene	Kjeldsen *et al.,* 2001;Kjeldsen *et al.,* 2003;Buttery and Takeoka, 2004; Cliffe-Byrnes *et al*., 2007; Kreutzmann *et al.,* 2008; Gutierrez *et al.,* 2009,
Humulene	Kjeldsen *et al.,* 2001;Wang *et al.,* 2001; Kjeldsen *et al.,* 2003; Cliffe-Byrnes *et al*., 2007; Kreutzmann *et al.,* 2008; Gutierrez *et al.,* 2009; Lonchamp *et al.,* 2009
Valencene	Kjeldsen *et al.,* 2001; Kjeldsen *et al.,* 2003; Lonchamp *et al.,* 2009
β-bisabolene	Kjeldsen *et al.,* 2003; Cliffe-Byrnes *et al.,* 2007; Kreutzmann *et al.,* 2008
Cuparene	Kjeldsen *et al.,* 2003; Cliffe-Byrnes *et al.,* 2007; Kreutzmann *et al.,* 2008
caryophyllene oxide	Kjeldsen *et al.,* 2001;Wang *et al.,* 2001; Kjeldsen *et al.,* 2003; Kreutzmann *et al.,* 2008; Lonchamp *et al.,* 2009
(*E*,*E*)-2,4-heptadienal	Kreutzmann *et al.,* 2008; Serrano *et al.,* 2009
γ-cadiene	Kreutzmann *et al.,* 2008; Gutierrez *et al.,* 2009
Longipinene	Gutierrez *et al.,* 2009; Lonchamp *et al.,* 2009
δ-elemene	Buttery *et al.,* 1987; Gutierrez *et al.,* 2009; Lonchamp *et al.,* 2009
γ-muurolene	Gutierrez *et al.,* 2009;

Appendix A: Volatiles previously identified in carrots, potatoes and tomatoes

Aroma Volatile	**Authors**
4,4,1-methylethylidene-bis phenol	Gutierrez *et al.*, 2009; Lonchamp *et al*., 2009
butylated hydroxytoulene	Gutierrez *et al.*, 2009; Lonchamp *et al*., 2009
trans-2-hexenal	Petró-Turza, 1987; Krumbien and Auerswald, 1998; Wang *et al*., 2001; Krumbien *et al*., 2004; Serrano *et al.*, 2009
cis-3-hexenal	Petró-Turza, 1987; Krumbien and Auerswald, 1998; Wang *et al*., 2001; Krumbien *et al*., 2004; Serrano *et al.*, 2009
Furfural	Petró-Turza, 1987; Burdock, 2002
Geranylacetone	Buttery *et al.*, 1987; Tandon *et al*., 2000; Krumbien *et al*., 2004
Octanoic acid	Hayase *et al.*, 1984; Petró-Turza, 1987; Burdock, 2002
Palmitic acid	Hayase *et al.*, 1984; Petró-Turza, 1987; Burdock, 2002
Nonanoic acid	Hayase *et al.*, 1984; Petró-Turza, 1987; Burdock, 2002
5-ethyl-2(5H)-furanone	Wang *et al.*, 2001; Buttery and Takeoka, 2004
2-carene	Buttery *et al.*, 1987; Wang *et al*., 2001;
Furaneol	Krumbien and Auerswald, 1998
2,4-diisocyanato-1-methylbenzene	Lonchamp *et al*., 2009
2,6-ditertbutyl-benzoquinone	Lonchamp *et al*., 2009
2,4-bis(1,1-dimethylethyl)-phenol	Lonchamp *et al*., 2009
1,4 dichlorobenzene	Lonchamp *et al*., 2009

Appendix B: Information Sheet

My name is Clare Gilsenan. I am a postgraduate student with Dublin Institute of Technology. I am currently undertaking research in the area Flavour Perception.

I am looking for volunteers to complete a short carrot sensory test. The whole process should not exceed **10** minutes. I would be very grateful for your co-operation.

For the sensory test you will be required to evaluate the appearance, aroma, texture and taste of 2 raw carrot samples.

Fresh raw carrot will be used in this taste test. **No extra ingredients have been added.**
If there is any reasonable **doubt** or **uncertainty** about the **safety** of the material you will **not be asked to taste it**.

Participation in the study is **strictly voluntary** and participants **can withdraw at any time, without giving a reason.**

If you have any **allergies,** please **make them known** to the researcher at this point**.**
If you are a **diabetic, or have a cold or sinusitis** please **do not participate** in this taste test. If you have **any illness** which you feel may compromise your health please **do not participate** in this test

<u>All information on the consent form will be kept confidential.</u>

If you have any further questions please contact **Clare Gilsenan**.

Appendix C: Consent Form

Researcher's Name: **Clare Gilsenan**	Title: **Ms**.
Faculty/School/Department: **Faculty of Tourism and Food, School of Culinary Arts and Food Technology**	
Title of Study: **An Investigation into Flavour Perception**	

To be completed by the: Volunteer

Please circle your response for each of the questions- All questions must be answered!

- Have you been fully informed/read the information sheet about this study? YES/NO
- Have you had an opportunity to ask questions and discuss this study? YES/NO
- Have you received satisfactory answers to all your questions? YES/NO
- Have you received enough information about this study and any associated health and safety implications if applicable? YES/NO
- Do you understand that you are free to withdraw from this study?
    - at any time? YES/NO
    - without giving a reason for withdrawing? YES/NO
    - without affecting your future relationship with the Institute? YES/NO
- Have you been informed that this consent form shall be kept in the confidence? YES/NO
- Can you confirm that you are able and satisfied to consume all of the listed ingredients? YES/NO
- Do you know of any reason why you should not part-take in this consumer taste trial? YES/NO
- Do you agree to take part in the above study? YES/NO
- Do you understand that if you have any further questions about the research or need to discuss it further, you can contact Clare Gilsenan YES/NO

I, the undersigned, have read and agree to the terms and conditions as outlined above.

Signed ______________________________________

Name in Block Letters_____________________________________

Date ___________________

Signature of Researcher _________________________________

Date ___________________

Appendix D: Recruitment Form

RECRUITMENT QUESTIONNAIRE FOR FLAVOUR PANELISTS

PERSONAL INFORMATION

NAME:____

ADDRESS:

____

____

____

PHONE NO: ____

EMAIL ADDRESS: ____

AGE: **19-25** ☐ **26-35** ☐ **36-45** ☐ **46-55** ☐ **56+** ☐

GENDER: **MALE** ☐ **FEMALE** ☐

AVAILABILITY

1. **WHEN ARE YOU AVAILABLE TO UNDERTAKE FLAVOUR TRAINING?**
   - **A WEEKDAY MORNING** ☐
   - **A WEEKDAY AFTERNOON** ☐
   - **A WEEKEND** ☐

If you ticked any of the boxes, please specify the day of the week and a suitable time you are available to take the training course.

____

____

HEALTH

1. DO YOU HAVE ANY OF THE FOLLOWING :

DENTURES ☐
DIABETES ☐
ORAL AND GUM DISEASE ☐
FOOD ALLERGIES ☐
HYPERTENSION ☐
ASTHMA ☐
COELIACS DISEASE ☐

2. DO YOU TAKE ANY MEDICATION WHICH MIGHT AFFECT YOUR SENSES?

____

____

3. DO YOU SMOKE?

YES ☐ NO ☐

THANK YOU FOR FILLING OUT THE QUESTIONNAIRE AND AGREEING TO PARTICIPATE IN THE SENSORY TRAINING AND TRIALS.

Appendix E: Screening Tests

Basic Taste Test

Instructions:

You will be presented with 4 coded samples. Taste each sample and place the code beside the category which most appropriately describes its taste.

Taste	Code
Sour	
Sweet	
Salty	
Bitter	

Intensity Ranking Test

Instructions:

You will be presented with a set of three samples. Taste all three samples and then rank them in order of increasing intensity of flavour. Identify the flavour. Repeat this process for further tests.

	Least Flavour	Moderate Flavour	Greatest Flavour	Identity of the Flavour
Test 1				
Test 2				
Test 3				

Identification of Odours

Instructions:

You will be presented with 4 coded samples. You are requested not to open an odour bottle until you are ready to start testing. Smell samples carefully, take three short sniffs. Complete the assessment of this odour before proceeding to the next sample.

Sample Code	Do you recognize this aroma? Yes	Do you recognize this aroma? No	Name of the odour, description of the odour or odour association
177			
256			
839			
749			

Texture Assessment

Instructions:

You will be presented with 4 coded samples Bite into all three samples and then rank them in order of juiciness. Repeat this process for further tests.

	Not at all Juicy	Moderately Juicy	Very Juicy
Test 1			
Test 2			
Test 3			

Appendix F: Sensory Training Materials

Taste Training-Descriptors and Standards [a]

Basic Taste	Reference Standards	Concentrations
Sweet	Sucrose Solution (g/L)	10.0, 20.0, 50.0, 100.0
Sour	Citric Acid Solution (g/L)	0.25, 0.5, 1.0, 1.5
Bitter	Caffeine Solution (g/L)	0.3, 0.6, 1.3, 2.6
Salty	Sodium Chloride Solution (g/L)	1.0, 2.0, 5.0, 10.0

[a] Meilgaard *et al.* (1999)

Odour Training-Descriptors and Standards [a]

Aroma Descriptor	Reference Standard
Vine	Tomato vine and leaves
Green	Green beans (snapped open), green tomato
Ripe	Ripe tomato
Earthy	Wet compost
Musty	Duster, canned corn
Tropical	Mango, pineapple
Floral	Jasmine essence, lavender essence
Fruity	Orange, Lemon

[a] Baldwin and Thompson. (2000)

Texture Training (Finger Feel Firmness) -Descriptors and Standards [a]

Level	Description
A	Just picked at the light red stage of maturity, very fresh, very firm
B	Picked at the light red maturation stage and stored for 2-3 days at 20°C, still remain very firm.
C	Stored Tomatoes, slightly soft. Their firmness is still good enough for making salads and slicing
D	Stored Tomatoes. Softer than Type “C”. Not suitable for salads. May be used for cooking or the production of tomato paste. Poor market quality
E	Overripe Tomatoes. These tomatoes are softer than type “D”. They could be used for cooking or the production of tomato paste. Very poor market quality.

[a] Batu. (2004)

Colour Training (Tomatoes) -Descriptors and Standards [a]

Colour	Class	Description [a]
0	Green	Entirely light to dark green, but mature
1	Breaker	First appearance of external pink, red or greenish yellow colour; not more than 10%
2	Quarter Ripe	Over 10% but not more than 30% red, pink or yellow orange
3	Half Ripe	Over 30% both not more than 60% pinkish or red
4	Light Orange	Over 60%, but no more than 70% red
5	Dark Orange	Over 70% red, but no more than 80% red
6	Orange Red	Over 80% red, but no more than 90% red
7	Red	Over 90% red; desirable table ripeness

[a] Institute of Food Research. (2006)

Appendix G: Demographic information about consumers who participated in sensory evaluations of organically farmed and conventionally produced vegetables

Characteristic	**Category**	**Panel 1[a]** **%**	**Panel 2[b]** **%**	**Panel 3[c]** **%**
Gender	*Male*	49	40	32
	Female	51	60	68
Age	*18-29*	45	45	50
	30-39	36	23	40
	40-49	15	26	7
	50+	4	6	3
Fresh Vegetable (Carrot, Potato, Tomato) Consumption	*Once or more daily*	17	23	6
	4-6 times/week	33	25	7
	2-3 times/week	29	38	18
	Once a week	21	15	69
Organic Food Consumption	*Daily*	3	5	1
	More than once a week	2	15	3
	Once a week	12	24	15
	Once a month	18	35	23
	Never	65	21	58

[a] 75 consumers participated in the taste test on organic and conventional fresh carrots
[b] 80 consumers participated in the taste test on organic and conventional baked potatoes
[c] 72 consumers in the taste test on organic and conventional fresh tomatoes